Many-task Computing:

Bridging the Gap between High-Throughput Computing and High-Performance Computing

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Acknowledgements

- Committee Members
  - Ian Foster (advisor)
  - Rick Stevens
  - Alex Szalay
- University of Chicago
  - Computer Science Department
  - Computational Institute
- Argonne National Laboratory
  - Math and Computer Science Division
  - Argonne Leadership Computing Facility
- NASA
  - Ames Research Center
  - Jerry C. Yan
- Over 60 collaborators

Distributed Systems Laboratory University of Chicago

http://dsl-wiki.cs.uchicago.edu/index.php/Main_Page

- Lead by Dr. Ian Foster
- Research Areas:
  - Distributed systems
  - Grid middleware
  - Grid applications
  - Designing, implementing, and evaluating systems, protocols, and applications
  - Data-intensive scientific computing
- People:
  - 1 faculty (Dr. Ian Foster)
  - 12 students
  - 2 research staff
  - 13 alumnis

Computation Institute
University of Chicago

http://www.ci.uchicago.edu/index.php

- People:
  - Director: Ian Foster
  - 70 faculty and scientists
  - 30 full-time professional staff
  - 14 graduate students
- Focus
  - Deep Supercomputing
  - Data Intensive Computing
  - Next Generation Cybertools
- Many high-impact projects
  - Open Science Grid
  - TeraGrid
  - Globus
  - National Microbial Pathogen Research Center
  - Social Informatics Data Grid
  - Chicago Biomedical Consortium

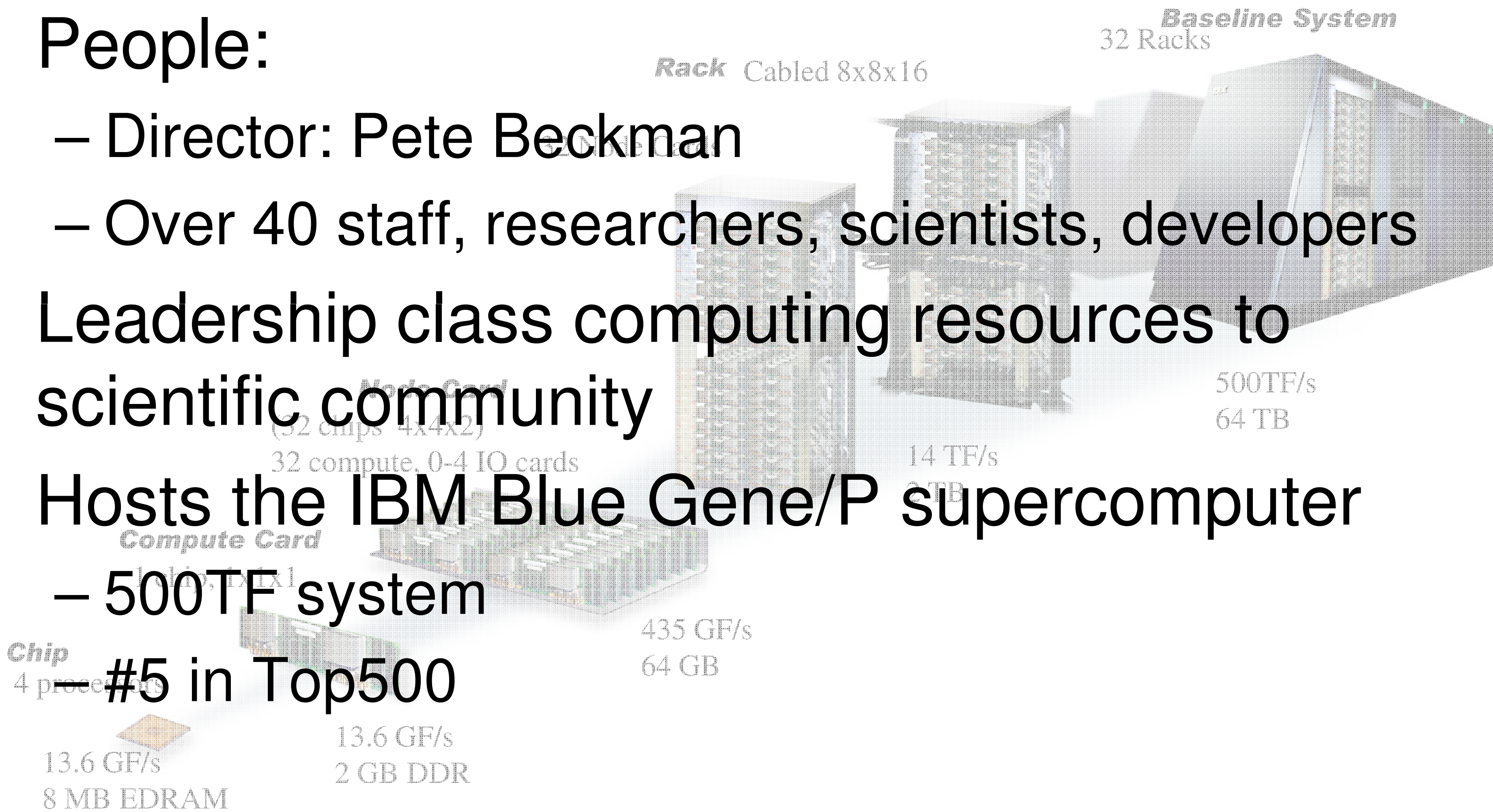
Math and Computer Science Div. Argonne National Laboratory

http://www.mcs.anl.gov/index.php

- People:
  - Associate Director: Ian Foster
  - Over 180 staff, researchers, scientists, developers
- Research Areas
  - Algorithms, Software, and Applications
  - Parallel Tools
  - Distributed Systems Research
  - Collaborative and Virtual Environments
  - Computational Science
- Many high-impact projects
  - TeraGrid (largest national cyber-infrastructure project)
  - Globus Toolkit (defacto Grid Computing midleware)
  - MPI (synonymous with HPC and Supercomputing)
  - PVFS (scalable and high performance parallel fie system)

Argonne Leadership Computing Facility Argonne National Laboratory

http://www.alcf.anl.gov/

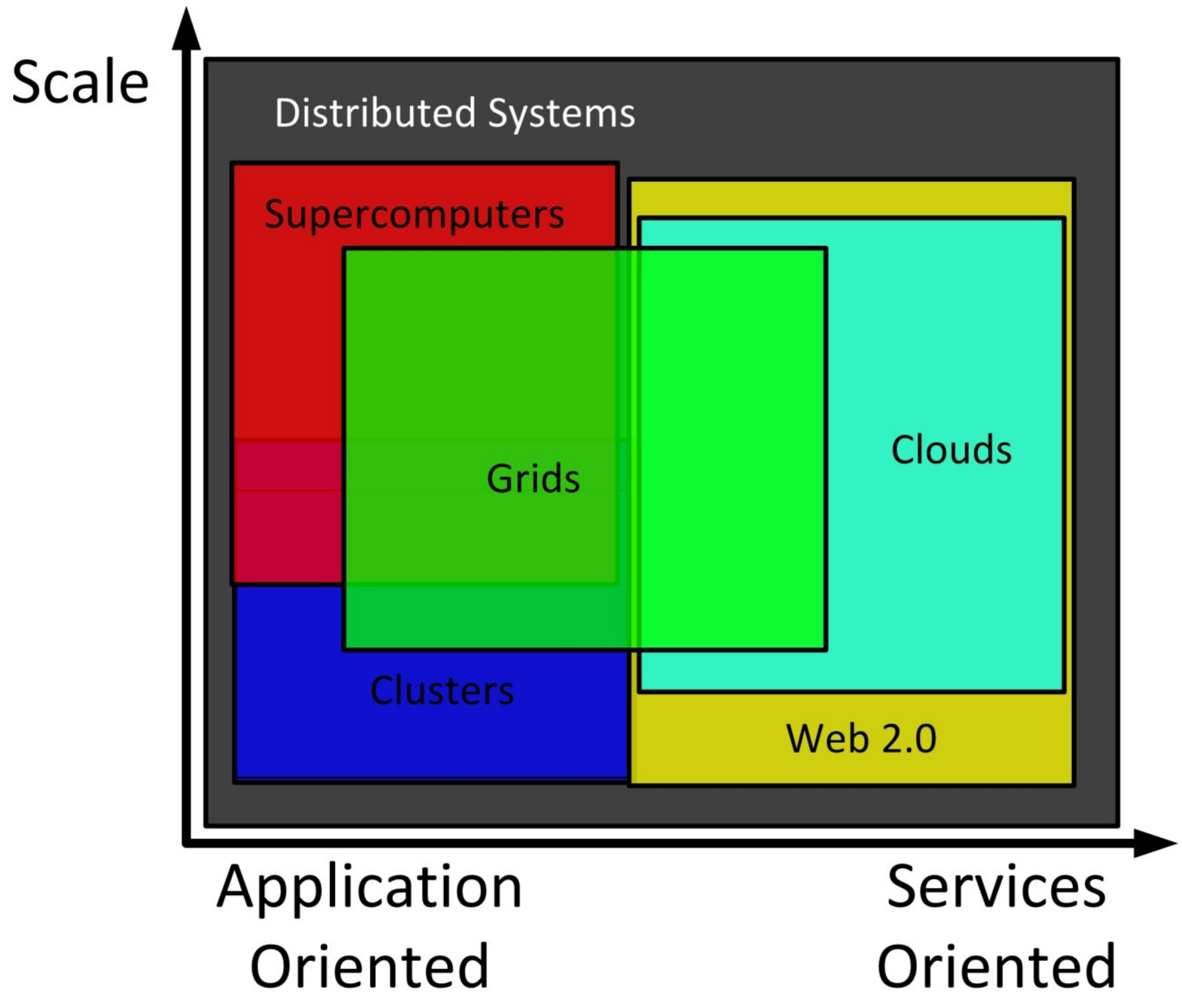


- People:
  - Director: Pete Beckman
  - Over 40 staff, researchers, scientists, developers
- Leadership class computing resources to scientific community
- Hosts the IBM Blue Gene/P supercomputer
  - 500TF system
  - #5 in Top500

Distributed Resources

- UChicago CS (50+ machines over the UChicago campus)
- UChicago TeraPort (274-cores)
- UC/ANL Cluster (316 processors)
- PlanetLab (912 nodes at 470 sites all over the world)
- UChicago PADS (7TF, 512-cores)
- ANL SiCortex 5832 (6TF, 5832-cores)
- Open Science Grid (43K-cores across 80 institutions in the US)
- IBM Blue Gene/P Supercomputer at ANL (~500TF, 160K-cores)
- TeraGrid (161K-cores across 11 institutions and 22 systems over the US)
  - Includes a Sun Constellation supercomputer (~500TF, 62K-cores)

Clusters, Grids, Supercomputers



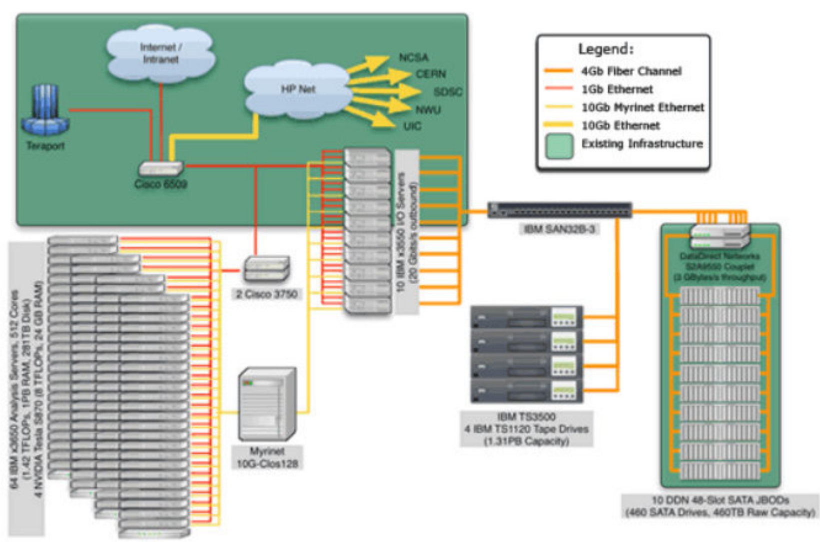
[GCE08] "Cloud Computing and Grid Computing 360-Degree Compared"

Cluster Computing: PADS

PADS

Computer clusters using commodity processors, network interconnects, and operating systems.

home



System diagram of the PADS environment, showing links to other resources.

PADS is a petabyte (10^{15}-byte)-scale online storage server capable of sustained multi-gigabyte/s I/O performance, tightly integrated with a 9 teraflop/s computing resource and multi-gigabit/s local and wide area networks. Its hardware and associated software enables the reliable storage of, access to, and analysis of massive datasets by both local users and the national scientific community.

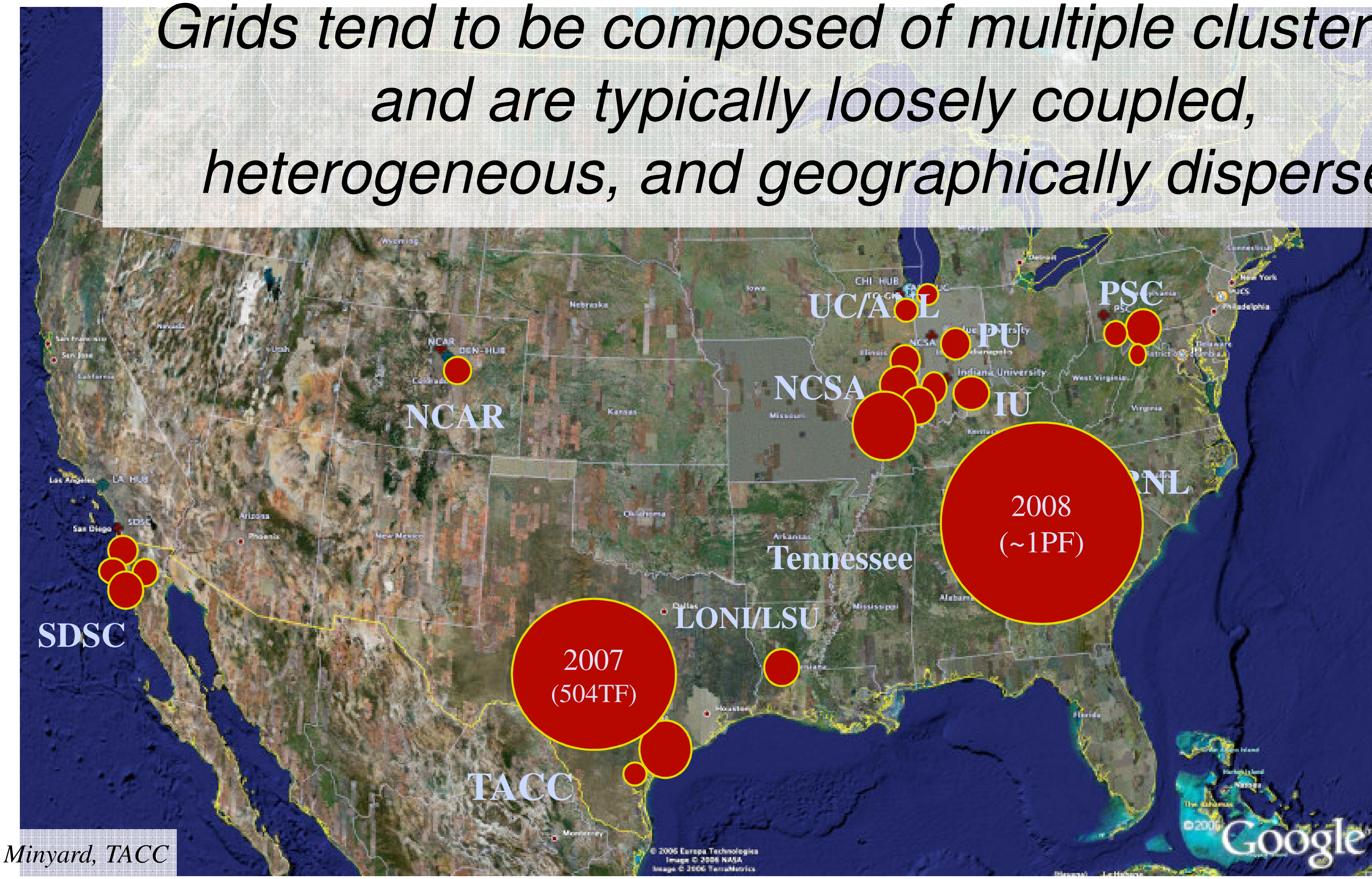
The PADS design results from a study of the storage and analysis requirements of participating groups in astrophysics and astronomy, computer science, economics, evolutionary and organismal biology, geosciences, high-energy physics, linguistics, materials science, neuroscience, psychology, and sociology. For these groups, PADS represents a significant opportunity to look at their data in new ways, enabling new scientific insights. The infrastructure also encourages new collaborations across disciplines. PADS is also a vehicle for computer science research into active data store systems, and provides rich data on which to investigate new techniques. Results will be made available as open source software.

The PADS project is supported in part by the National Science Foundation under grant OCI-0821678 and by The University of Chicago.

PADSstatus myPADS

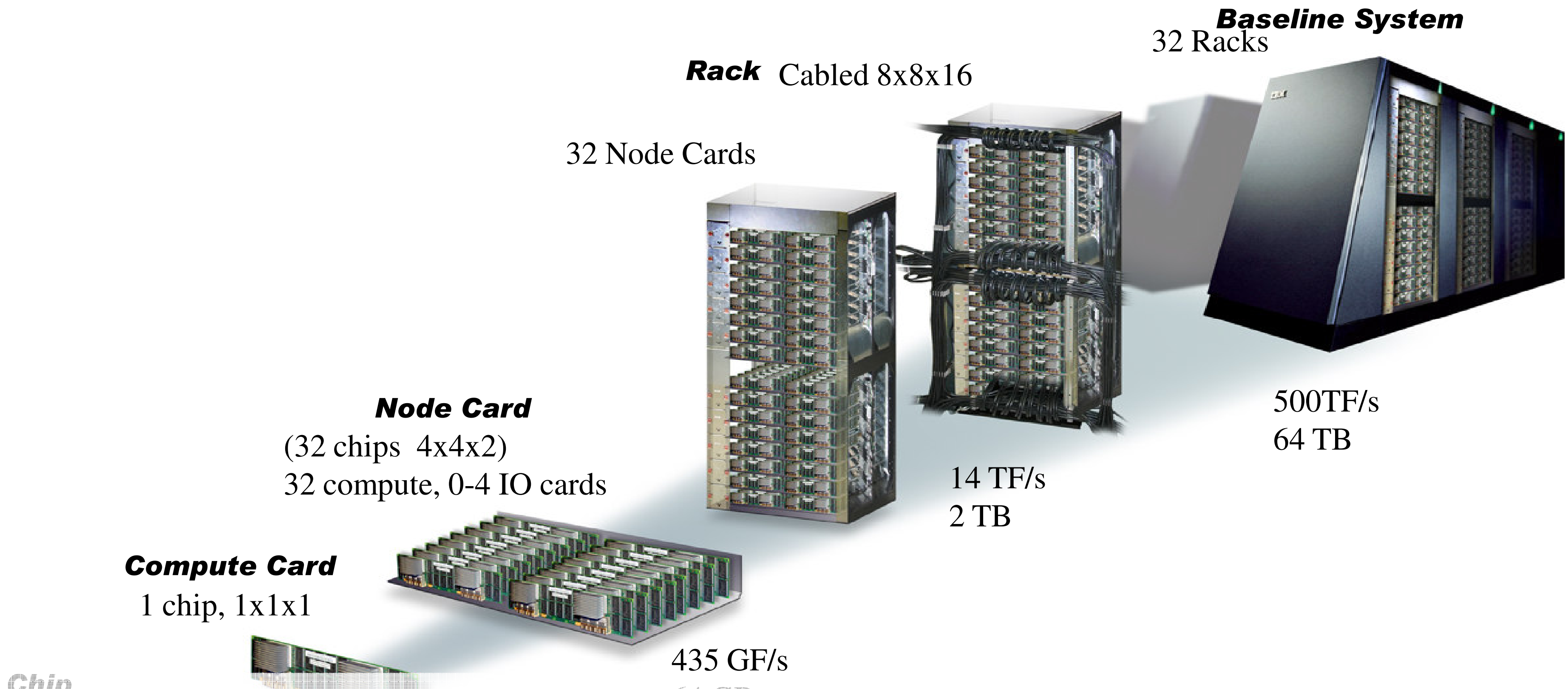
Grid Computing: TeraGrid

Grids tend to be composed of multiple clusters, and are typically loosely coupled, heterogeneous, and geographically dispersed



Tommy Minyard, TACC

Supercomputing: IBM Blue Gene/P



Highly-tuned computer clusters using commodity processors combined with custom network interconnects and customized operating system

High-Throughput Computing & High-Performance Computing

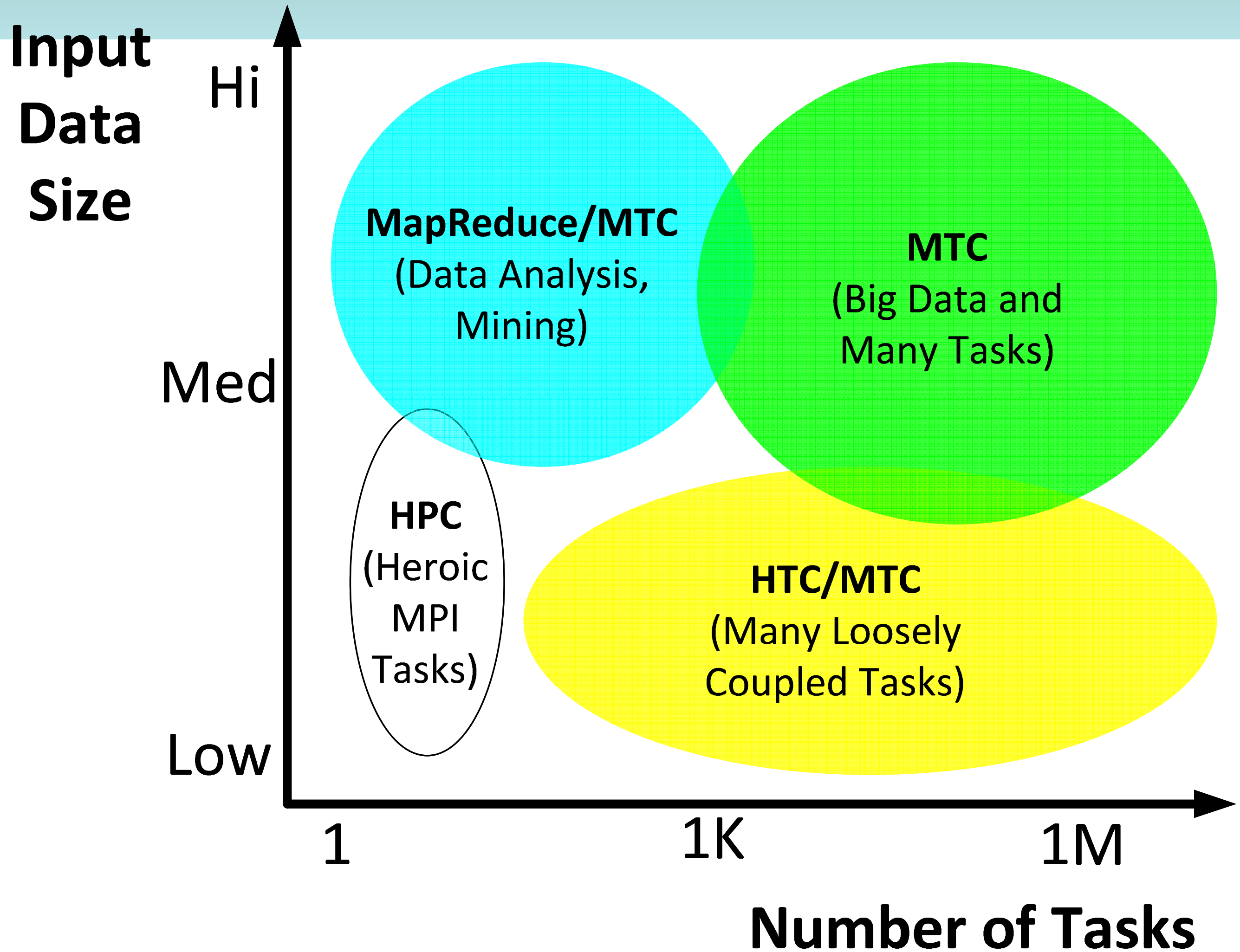
- HTC: High-Throughput Computing
  - Typically applied in clusters and grids
  - Loosely-coupled applications with sequential jobs
  - Large amounts of computing for long periods of times
  - Measured in operations per month or years
- HPC: High-Performance Computing
  - Synonymous with supercomputing
  - Tightly-coupled applications
  - Implemented using Message Passing Interface (MPI)
  - Large of amounts of computing for short periods of time
  - Usually requires low latency interconnects
  - Measured in FLOPS

MTC: Many-Task Computing

- Bridge the gap between HPC and HTC
- Applied in clusters, grids, and supercomputers
- Loosely coupled apps with HPC orientations
- Many activities coupled by file system ops
- Many resources over short time periods
  – Large number of tasks, large quantity of computing, and large volumes of data

[MTAGS08 Workshop] Workshop on Many-Task Computing on Grids and Supercomputers 2008
[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"
[MTAGS08] "Many-Task Computing for Grids and Supercomputers"

Problem Space

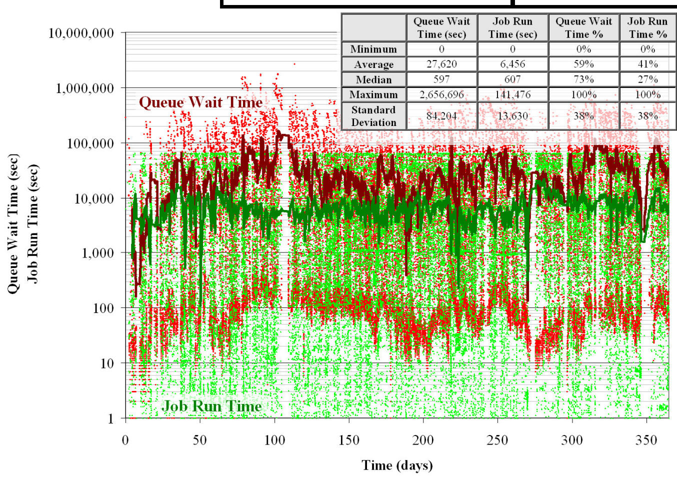


[MTAGS08] "Many-Task Computing for Grids and Supercomputers"

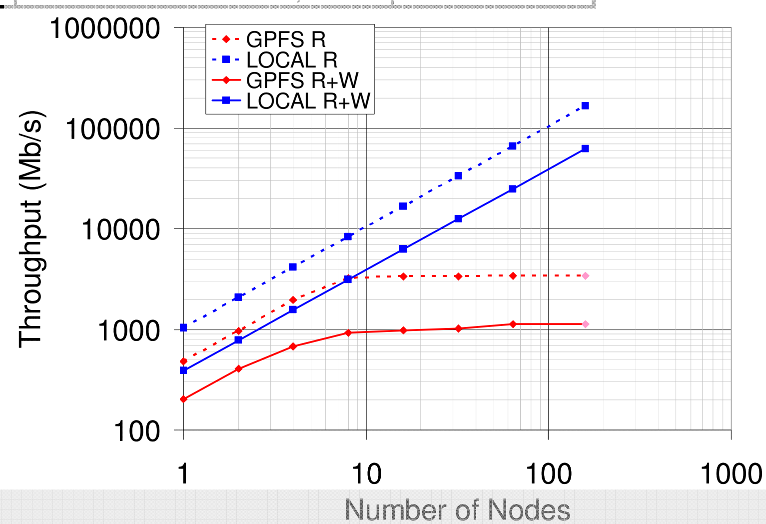
Challenges for MTC

1. Slow job dispatch rates
2. Long queue times
3. Poor shared/parallel file system scaling

System	Comments	Throughput (tasks/sec)
Condor (v6.7.2) - Production	Dual Xeon 2.4GHz, 4GB	0.49
PBS (v2.1.8) - Production	Dual Xeon 2.4GHz, 4GB	0.45
Condor (v6.7.2) - Production	Quad Xeon 3 GHz, 4GB	2
Condor (v6.8.2) - Production		0.42
Condor (v6.9.3) - Development		11
Condor-J2 - Experimental	Quad Xeon 3 GHz, 4GB	22

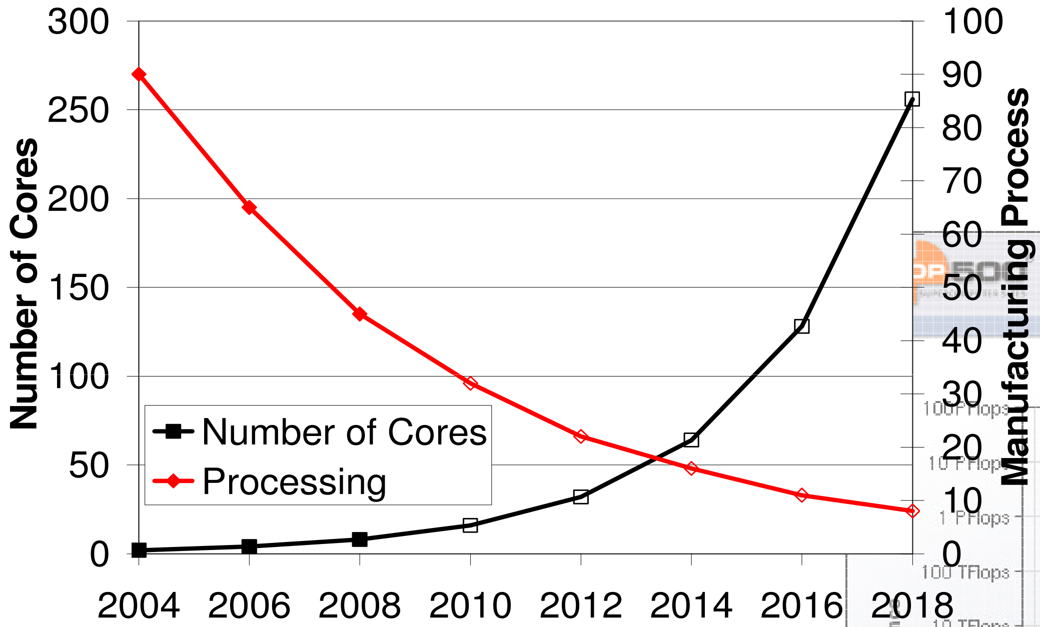


	Queue Wait Time (sec)	Job Run Time (sec)	Queue Wait Time %	Job Run Time %
Minimum	0	0	0%	0%
Average	27,620	6,456	59%	41%
Median	597	607	73%	27%
Maximum	2,656,696	141,476	100%	100%
Standard Deviation	84,204	13,630	38%	38%

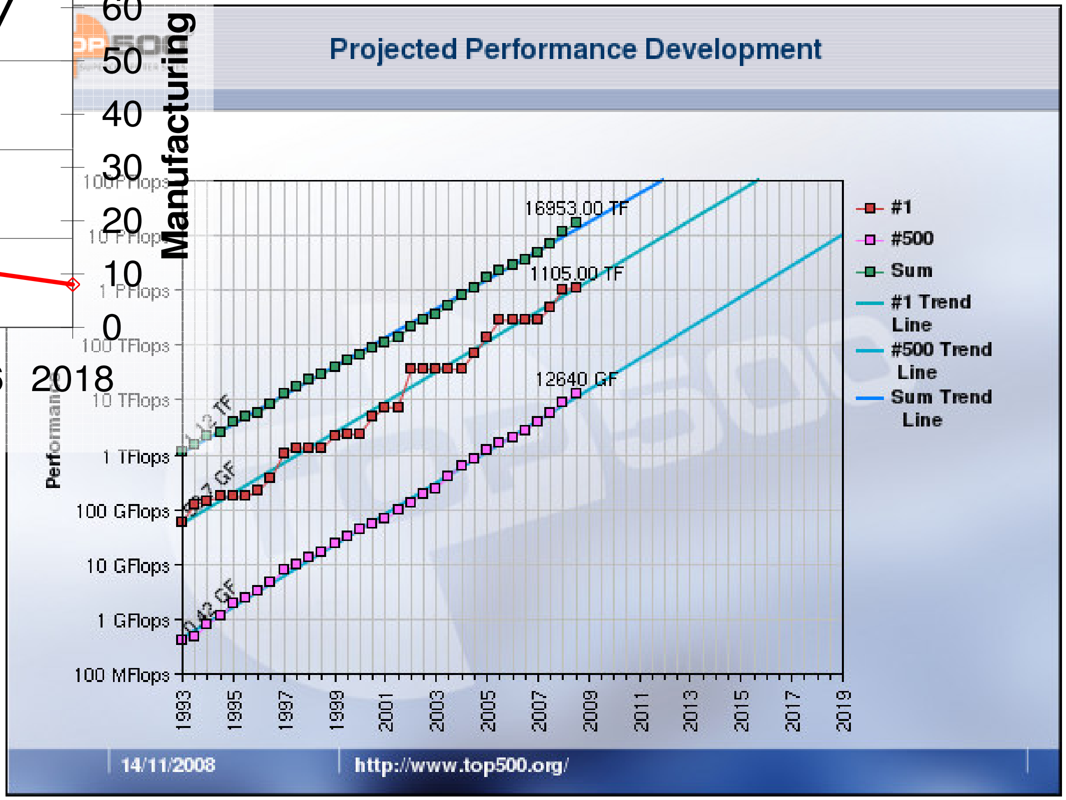


[UC07] "Harnessing Grid Resources with Data-Centric Task Farms"

Projected Growth Trends



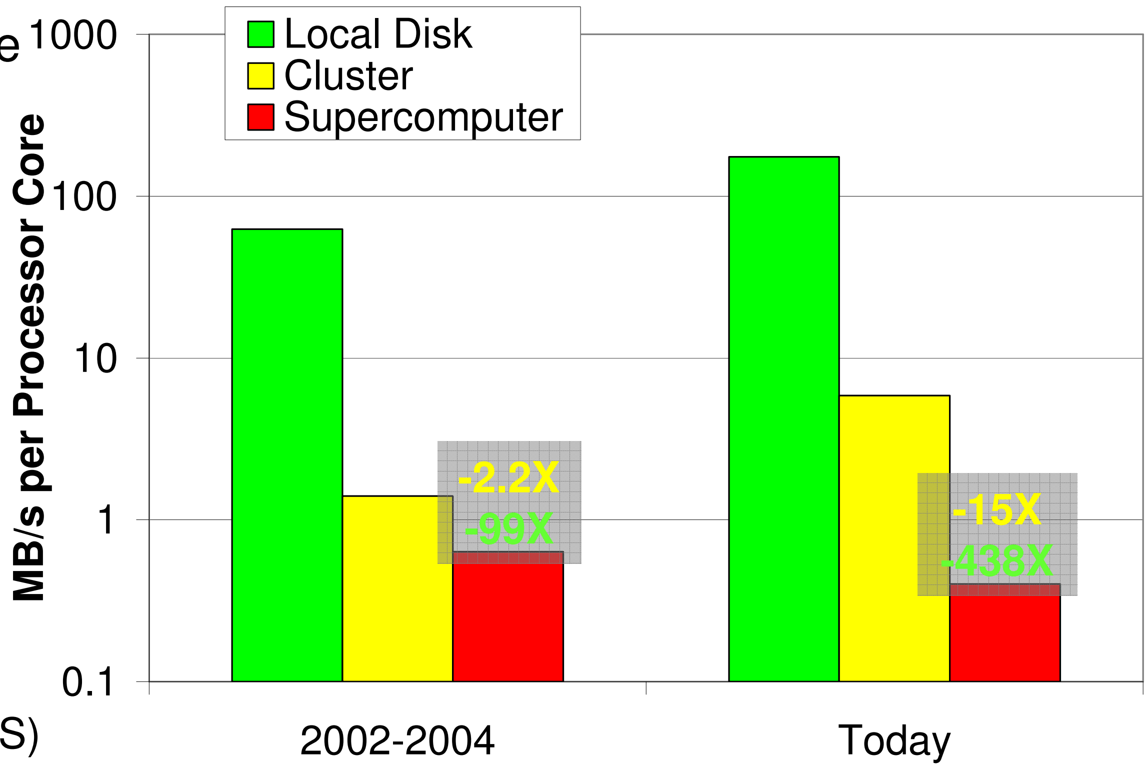
Pat Helland, Microsoft, The Irresistible Forces Meet the Movable Objects, November 9th, 2007



Top500 Projected Development,
http://www.top500.org/lists/2008/11/performance_development

Growing Storage/Compute Gap

- Local Disk:
  - 2002-2004: ANL/UC TG Site (70GB SCSI)
  - Today: PADS (RAID-0, 6 drives 750GB SATA)
- Cluster:
  - 2002-2004: ANL/UC TG Site (GPFS, 8 servers, 1Gb/s each)
  - Today: PADS (GPFS, SAN)
- Supercomputer:
  - 2002-2004: IBM Blue Gene/L (GPFS)
  - Today: IBM Blue Gene/P (GPFS)



Presentation Focus

- [JS09] “Middleware Support for Many-Task Computing”, under preparation
- [HPDC09] “The Quest for Scalable Support of Data Intensive Workloads in Distributed Systems”, under review
- [DIDC09] “Towards Data Intensive Many-Task Computing” , under review
- [SC08] “Towards Loosely-Coupled Programming on Petascale Systems”
- [MTAGS08 Workshop] Workshop on Many-Task Computing on Grids and Supercomputers
- [MTAGS08] “Many-Task Computing for Grids and Supercomputers”
- [MTAGS08] “Design and Evaluation of a Collective I/O Model for Loosely-coupled Petascale Programming”
- [GCE08] “Cloud Computing and Grid Computing 360-Degree Compared”
- [SWF08] “Scientific Workflow Systems for 21st Century e-Science, New Bottle or New Wine?”
- [DADC08] “Accelerating Large-scale Data Exploration through Data Diffusion”
- [TG08] “Data Intensive Scalable Computing on TeraGrid: A Comparison of MapReduce and Swift”
- [GlobusWorld08] “Managing and Executing Loosely Coupled Large Scale Applications on Clusters, Grids, and Supercomputers”
- [NOVA08] “Realizing Fast, Scalable and Reliable Scientific Computations in Grid Environments”
- [UC07] “Harnessing Grid Resources with Data-Centric Task Farms”
- [Globus07] “Falkon: A Proposal for Project Globus Incubation”
- [SC07] “Falkon: a Fast and Light-weight tasK executiON framework”
- [MSES07] “A Data Diffusion Approach to Large Scale Scientific Exploration”
- [SWF07] “Swift: Fast, Reliable, Loosely Coupled Parallel Computation”
- [TG07] “Dynamic Resource Provisioning in Grid Environments”
- [NASA06-08] “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets”
- [SC06] “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets”
- [TG06] “AstroPortal: A Science Gateway for Large-scale Astronomy Data Analysis”
- [NSF06] “The Importance of Data Locality in Distributed Computing Applications”

Techniques to Support MTC

- Streamlined task dispatching
- Dynamic resource provisioning
  - Multi-level scheduling
  - Resources are acquired/released in response to demand
- Data diffusion
  - Data diffuses from archival storage to transient resources
  - Resource "caching" allows faster responses to subsequent requests
  - Co-locate data and computations to optimize performance

[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"
[DADC08] "Accelerating Large-scale Data Exploration through Data Diffusion"
[UC07] "Harnessing Grid Resources with Data-Centric Task Farms"
[SC07] "Falkon: a Fast and Light-weight tasK executiON framework"
[TG07] "Dynamic Resource Provisioning in Grid Environments"

Theoretical and Practical Exploration

- Abstract model
  - Models the efficiency and speedup of entire workloads
  - Captures techniques to support MTC
    - Streamlined task dispatching
    - Dynamic resource provisioning
    - Data diffusion
- Middleware to support MTC
  - Falkon: a fast a light-weight execution framework
  - Reference Implementation of the abstract model

[JS09] “Middleware Support for Many-Task Computing”, under preparation
[DIDC09] “Towards Data Intensive Many-Task Computing”, under review
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Middleware Support: Falkon

- ***Goal:*** enable the ***rapid and efficient*** execution of many independent jobs on large compute clusters
- Combines three components:
  - a ***streamlined task dispatcher***
  - ***resource provisioning*** through multi-level scheduling techniques
  - ***data diffusion*** and data-aware scheduling to leverage the co-located computational and storage resources
- Integration into Swift to leverage many applications
  - Applications cover many domains: astronomy, astro-physics, medicine, chemistry, economics, climate modeling, etc

[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"
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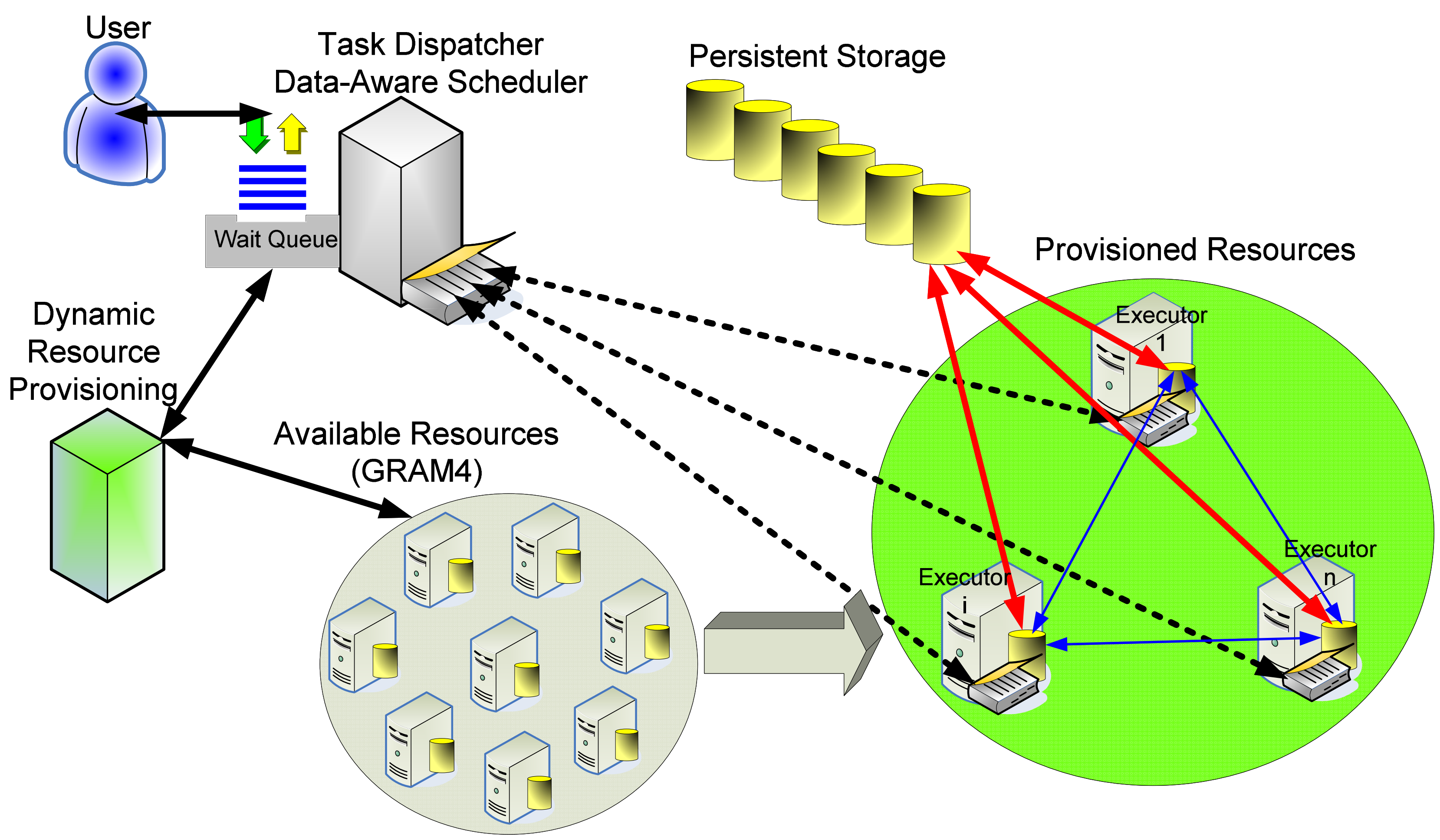
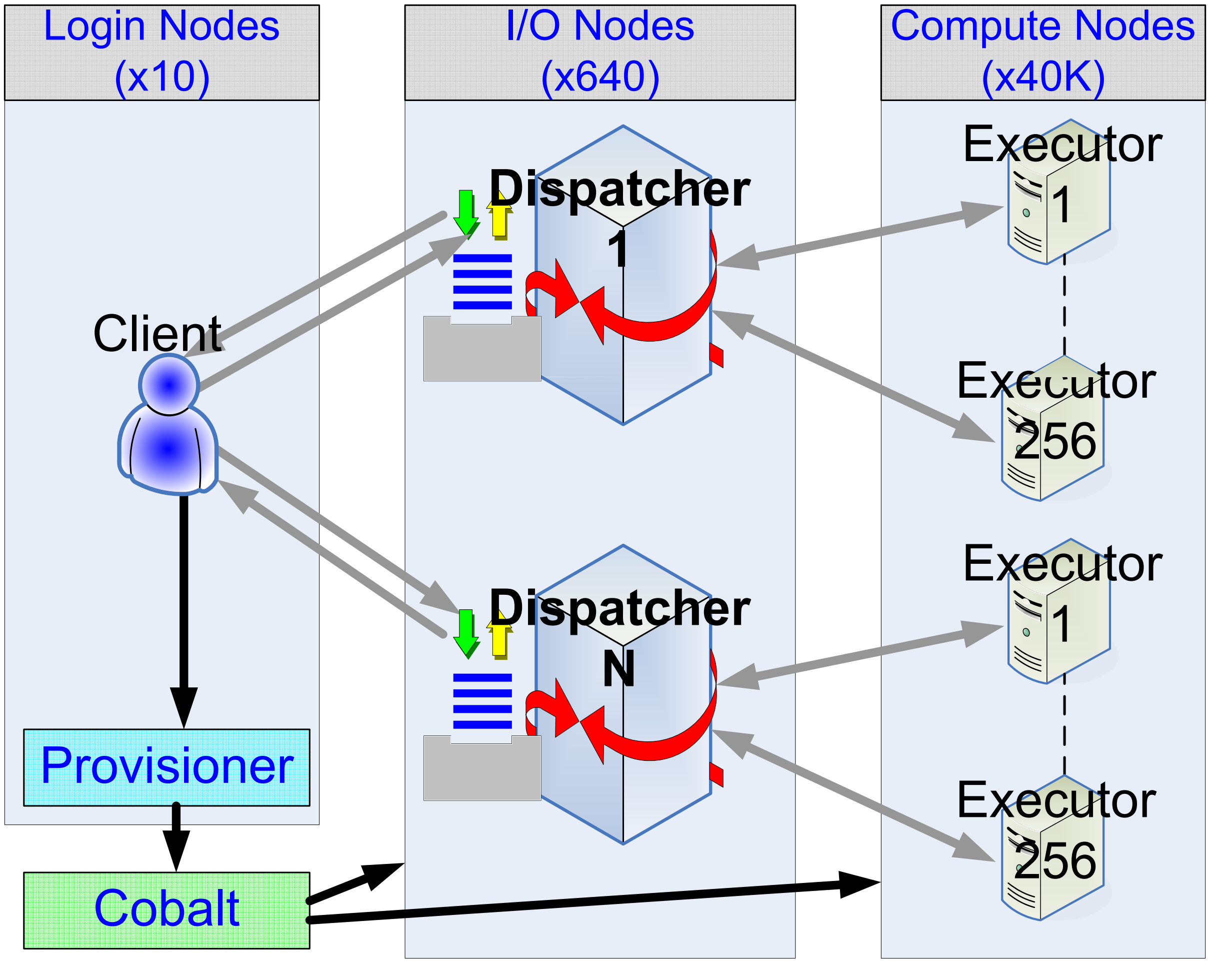
[SWF07] "Swift: Fast, Reliable, Loosely Coupled Parallel Computation"

Falkon Architecture



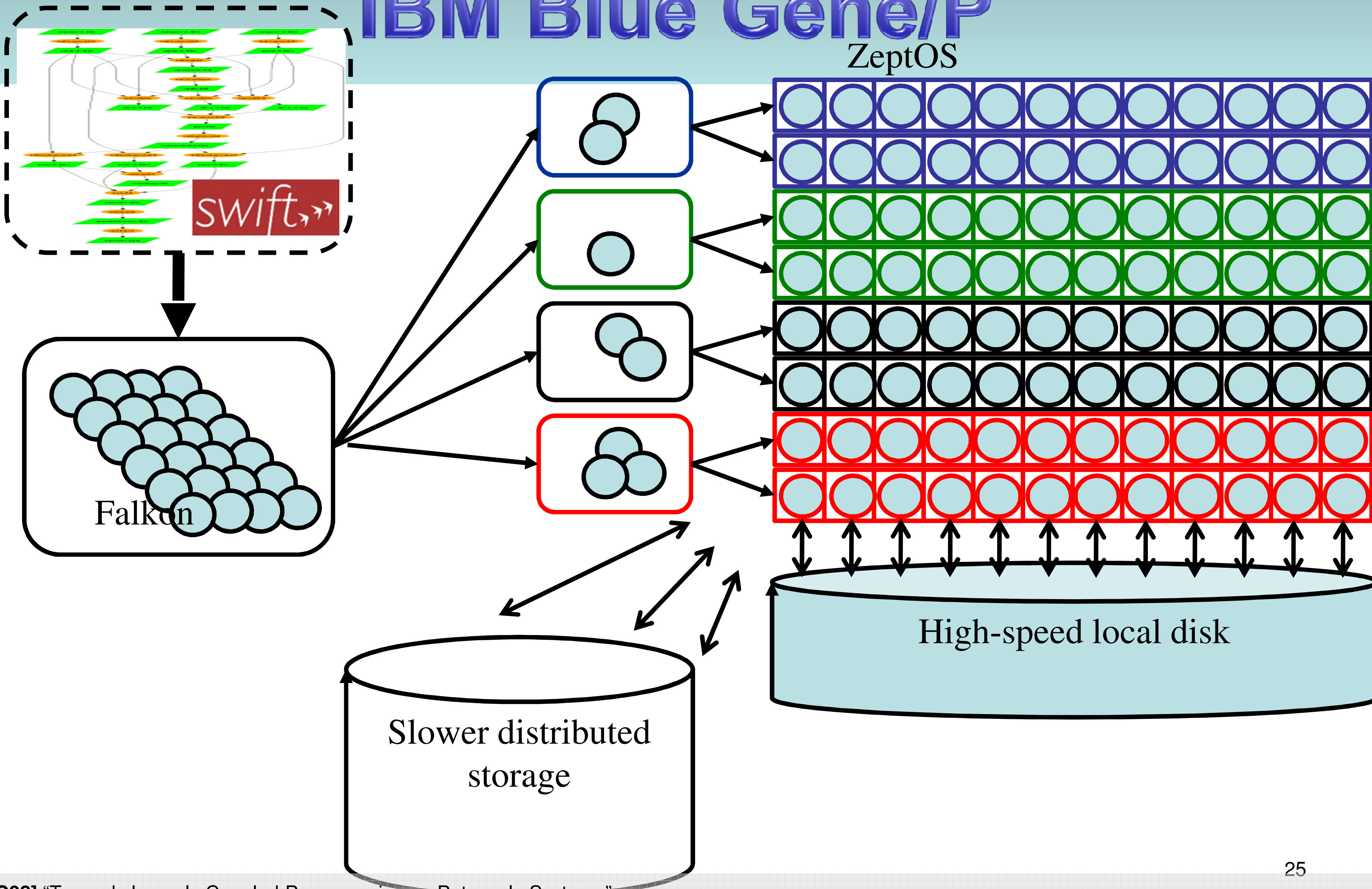
[SC07] "Falkon: a Fast and Light-weight tasK executiON framework"

Distributed Falkon Architecture



[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"

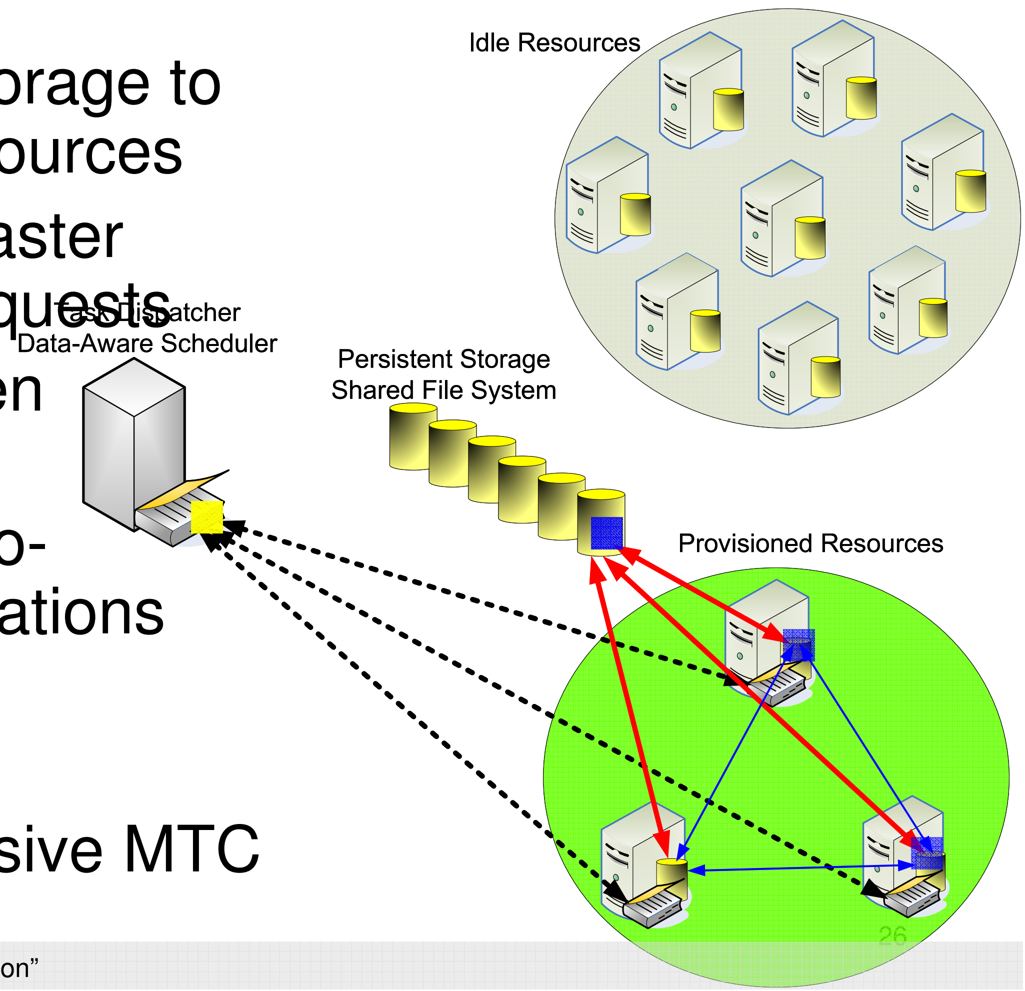
Managing 160K CPUs IBM Blue Gene/P



[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"

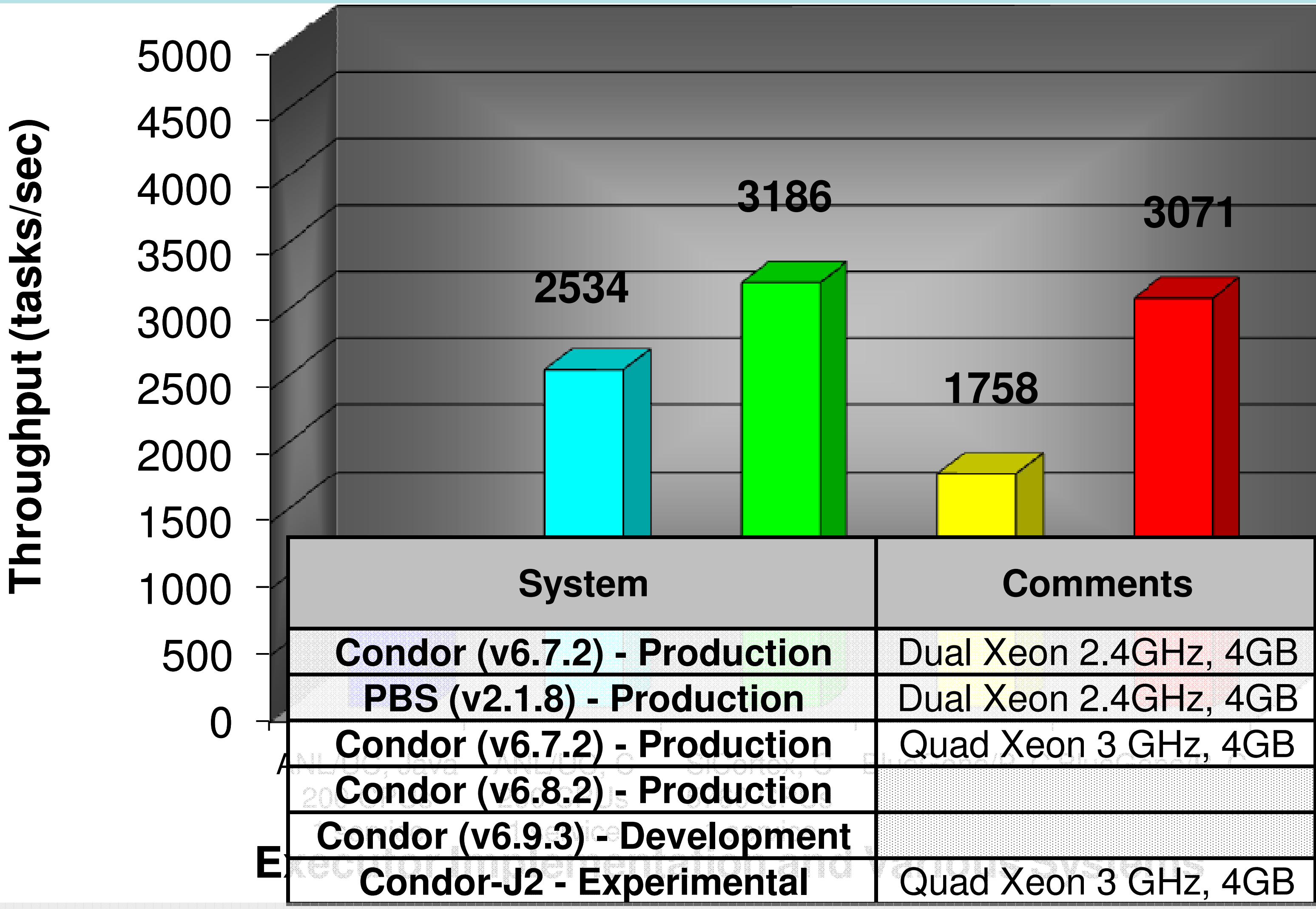
Data Diffusion

- Resource acquired in response to demand
- Data diffuse from archival storage to newly acquired transient resources
- Resource "caching" allows faster responses to subsequent requests
- Resources are released when demand drops
- Optimizes performance by co-scheduling data and computations
- Decrease dependency of a shared/parallel file systems
- Critical to support data intensive MTC



[DADC08] "Accelerating Large-scale Data Exploration through Data Diffusion"

Dispatch Throughput



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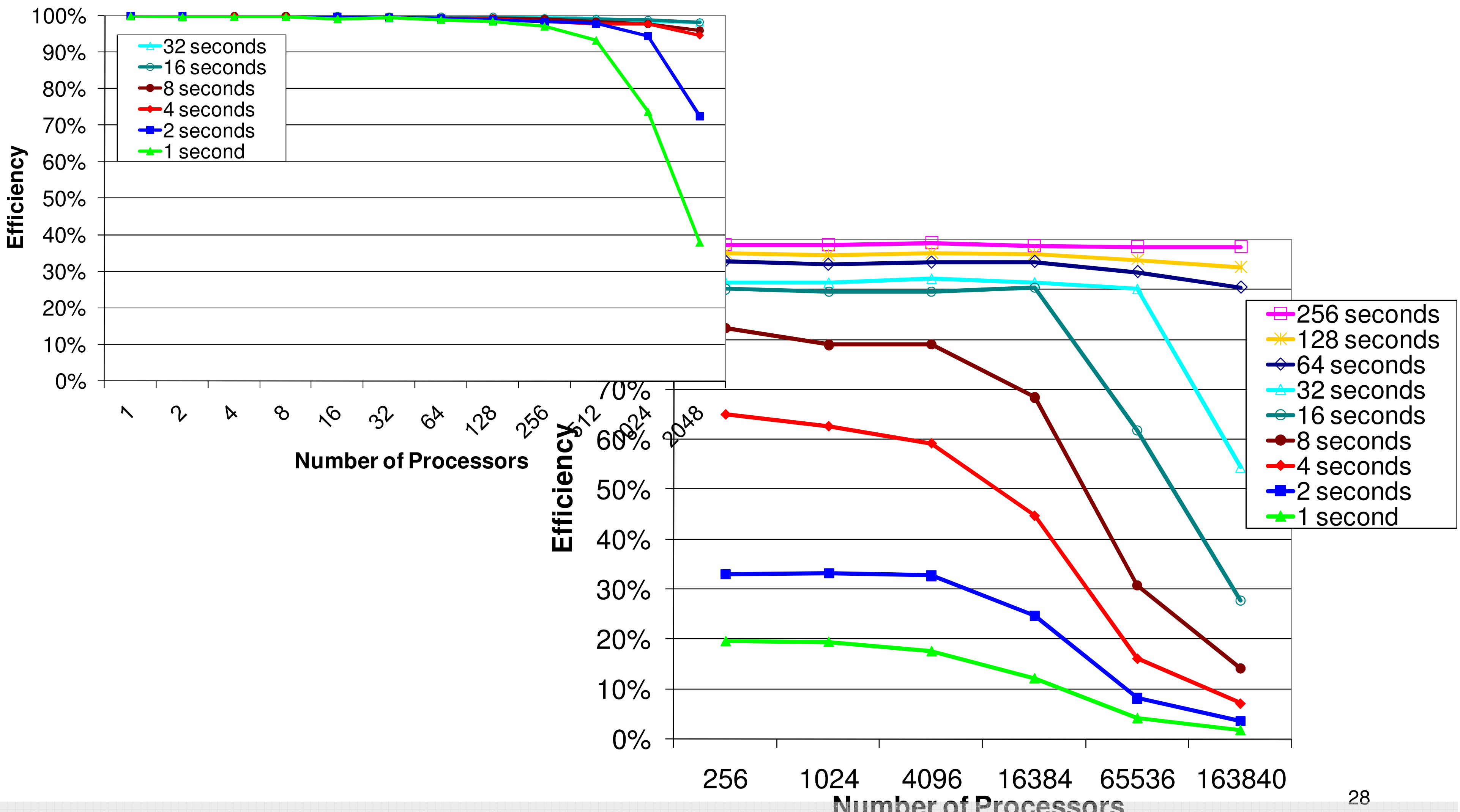
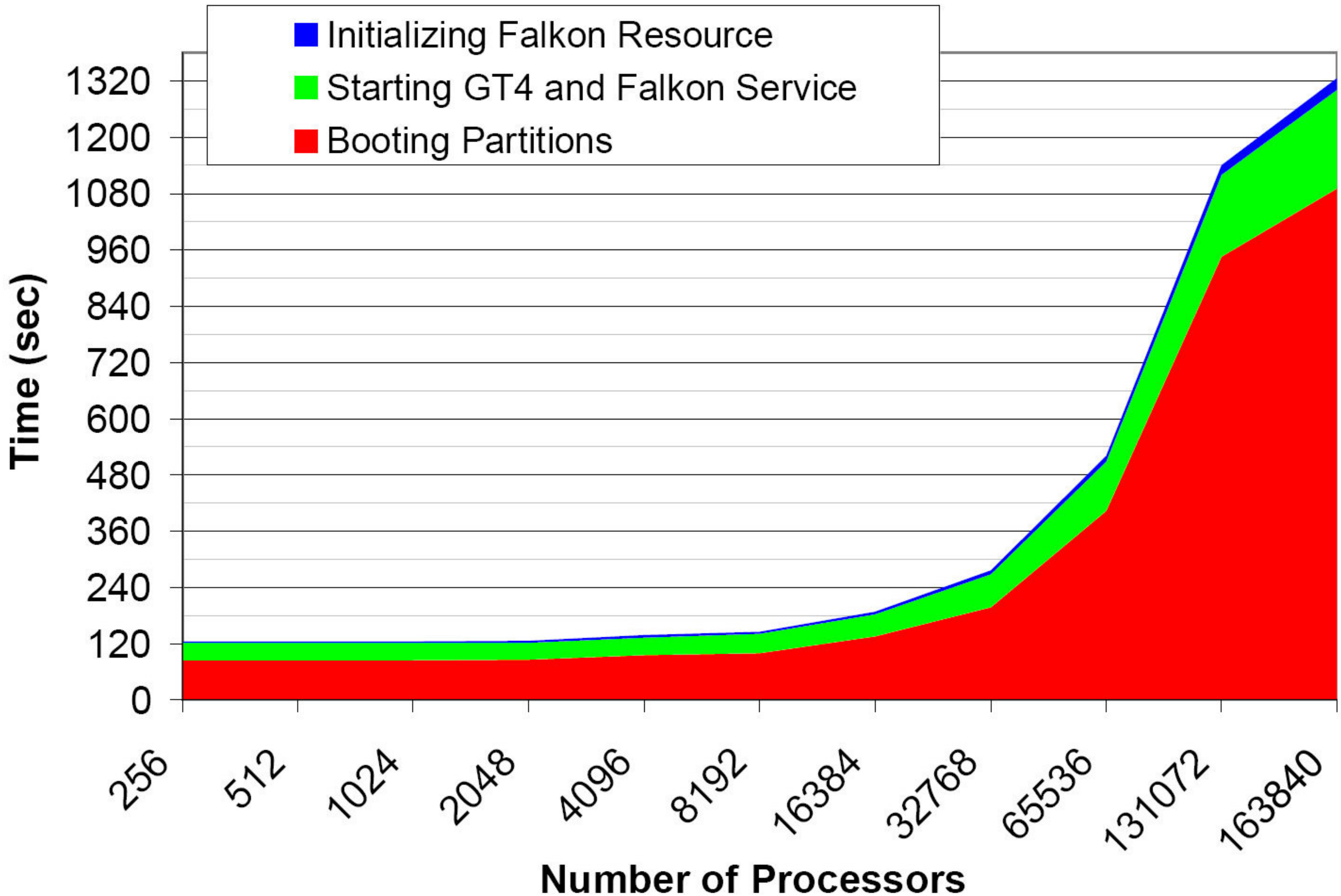
[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"

Execution Efficiency



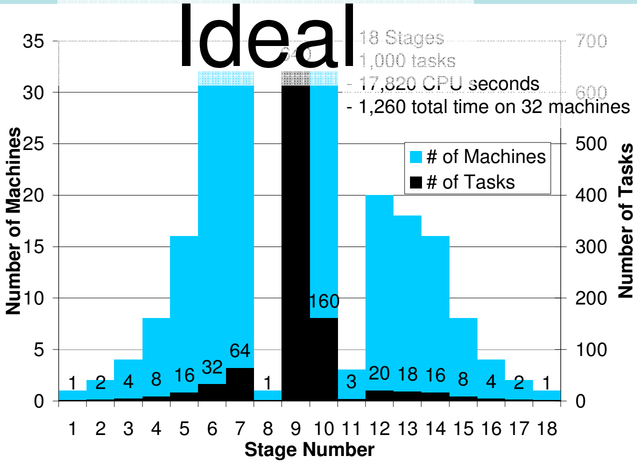
[SC08] “Towards Loosely-Coupled Programming on Petascale Systems”

Resource Provisioning Overheads IBM Blue Gene/P

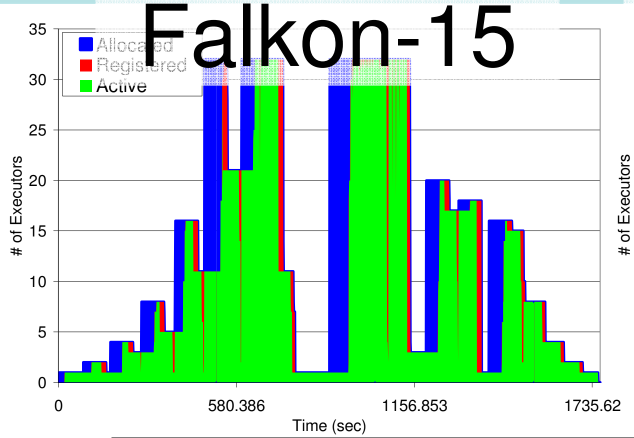


Dynamic Resource Provisioning

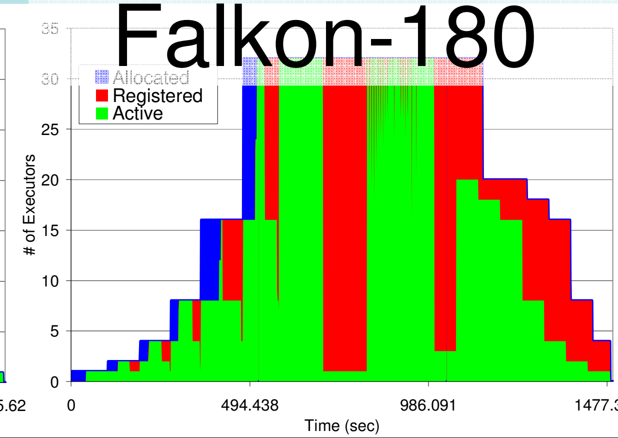
Ideal



Falkon-15



Falkon-180



- End-to-end execution time:
  - 1260 sec in ideal case
  - 4904 sec → 1276 sec
- Average task queue time:
  - 42.2 sec in ideal case
  - 611 sec → 43.5 sec
- Trade-off:
  - Resource Utilization for Execution Efficiency

	GRAM +PBS	Falkon-15	Falkon-60	Falkon-120	Falkon-180	Falkon-∞	Ideal (32 nodes)
Queue Time (sec)	611.1	87.3	83.9	74.7	44.4	43.5	42.2
Execution Time (sec)	56.5	17.9	17.9	17.9	17.9	17.9	17.8
Execution Time %	8.5%	17.0%	17.6%	19.3%	28.7%	29.2%	29.7%

	GRAM +PBS	Falkon-15	Falkon-60	Falkon-120	Falkon-180	Falkon-∞	Ideal (32 nodes)
Time to complete (sec)	**4904**	**1754**	**1680**	**1507**	**1484**	**1276**	**1260**
Resouce Utilization	30%	89%	75%	65%	59%	44%	100%
Execution Efficiency	26%	72%	75%	84%	85%	99%	100%
Resource Allocations	1000	11	9	7	6	0	0

[SC07] "Falkon: a Fast and Light-weight tasK executiON framework"

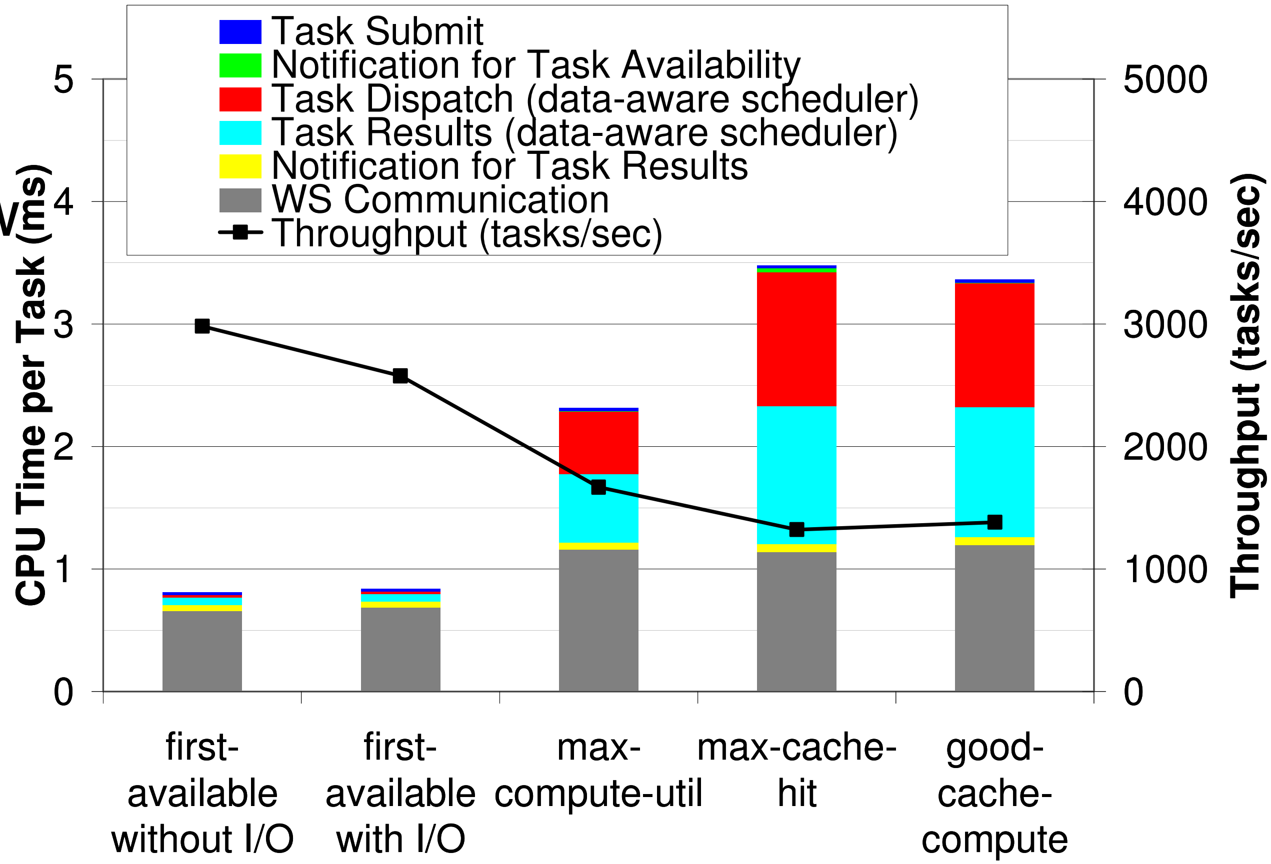
Scheduling Policies

- FA: first-available
  - simple load balancing
- MCH: max-cache-hit
  - maximize cache hits
- MCU: max-compute-util
  - maximize processor utilization
- GCC: good-cache-compute
  - maximize both cache hit and processor utilization at the same time

[DADC08] “Accelerating Large-scale Data Exploration through Data Diffusion”
[HPDC09] “The Quest for Scalable Support of Data Intensive Applications in Distributed Systems”, under review
[DIDC09] “Towards Data Intensive Many-Task Computing”, under review

Data-Aware Scheduler Profiling

- 3GHz dual CPUs
- ANL/UC TG with 128 processors
- Scheduling window 2500 tasks
- Dataset
  - 100K files
  - 1 byte each
- Tasks
  - Read 1 file
  - Write 1 file



[DIDC09] "Towards Data Intensive Many-Task Computing", under review

Synthetic Workloads

- Monotonically Increasing Workload
  - Emphasizes increasing loads
- Sine-Wave Workload
  - Emphasizes varying loads
- All-Pairs Workload
  - Compare to best case model of active storage
- Image Stacking Workload (Astronomy)
  - Evaluate data diffusion on a real large-scale data-intensive application from astronomy domain

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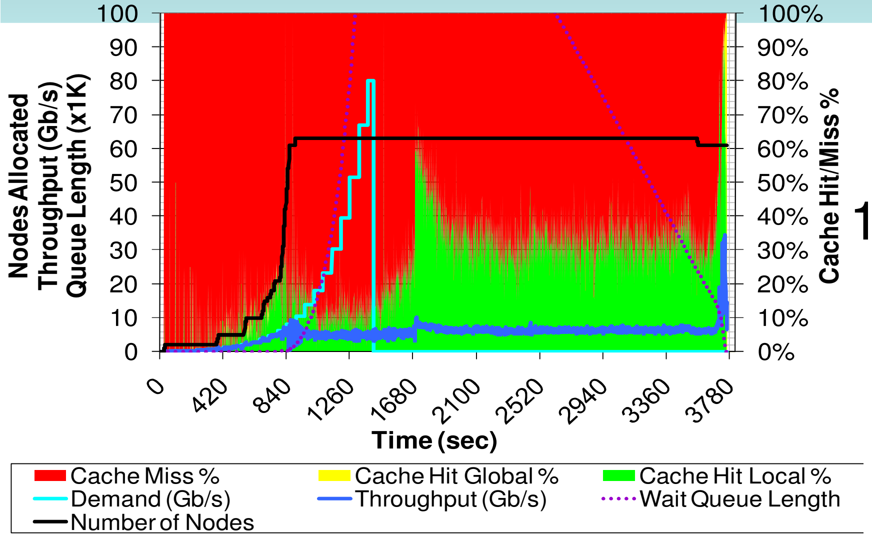
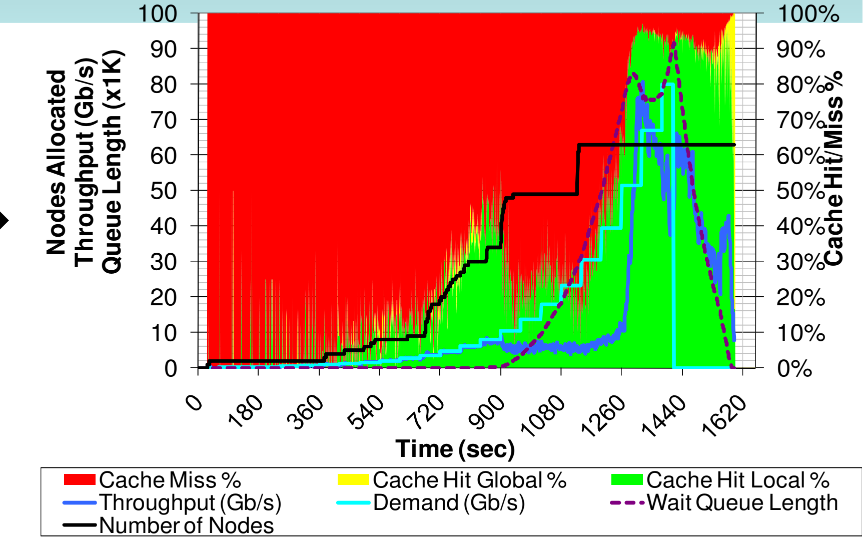
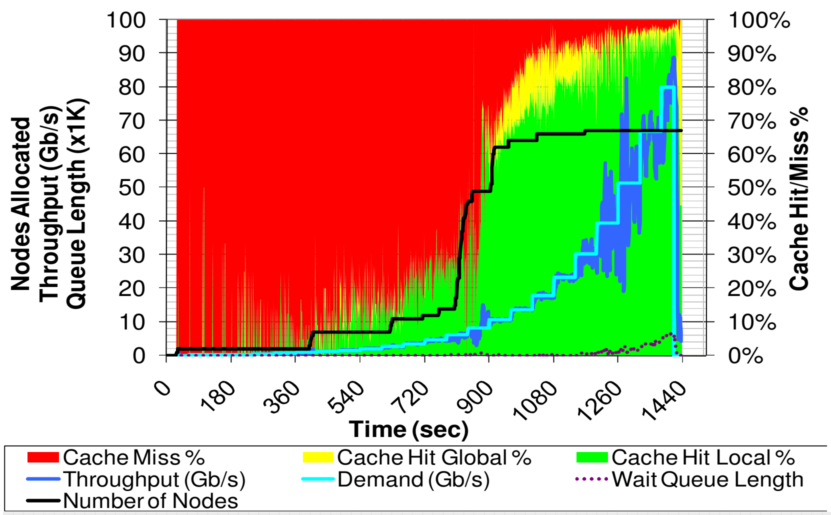
Data Diffusion
Monotonically Increasing Workload



← 1GB

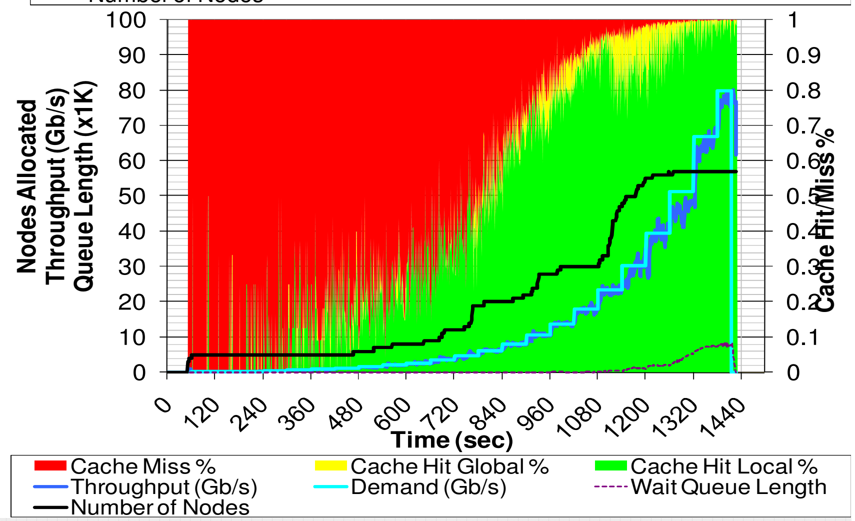
1.5GB →





← 2GB

4GB →



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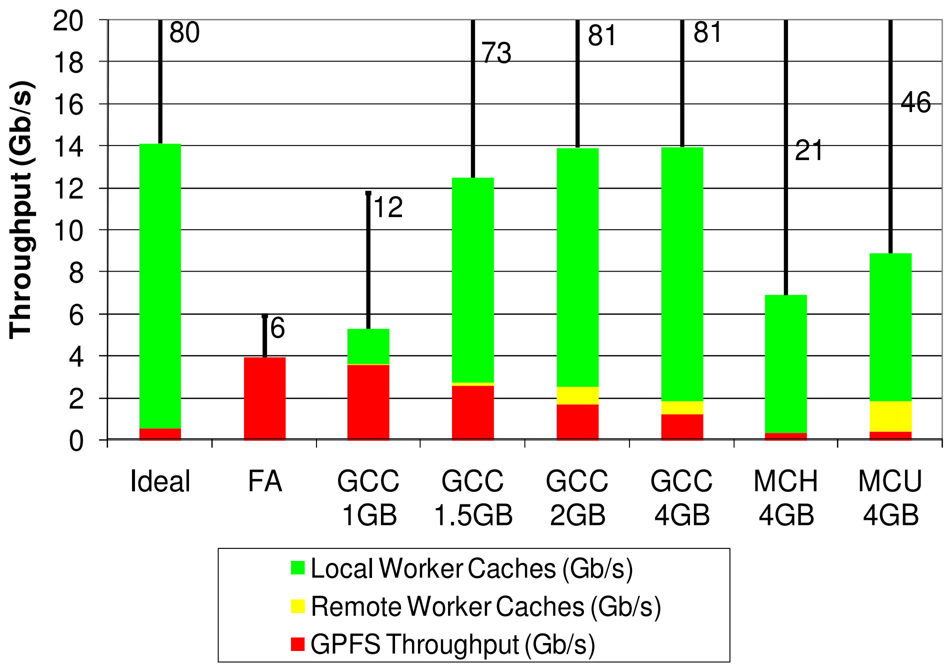
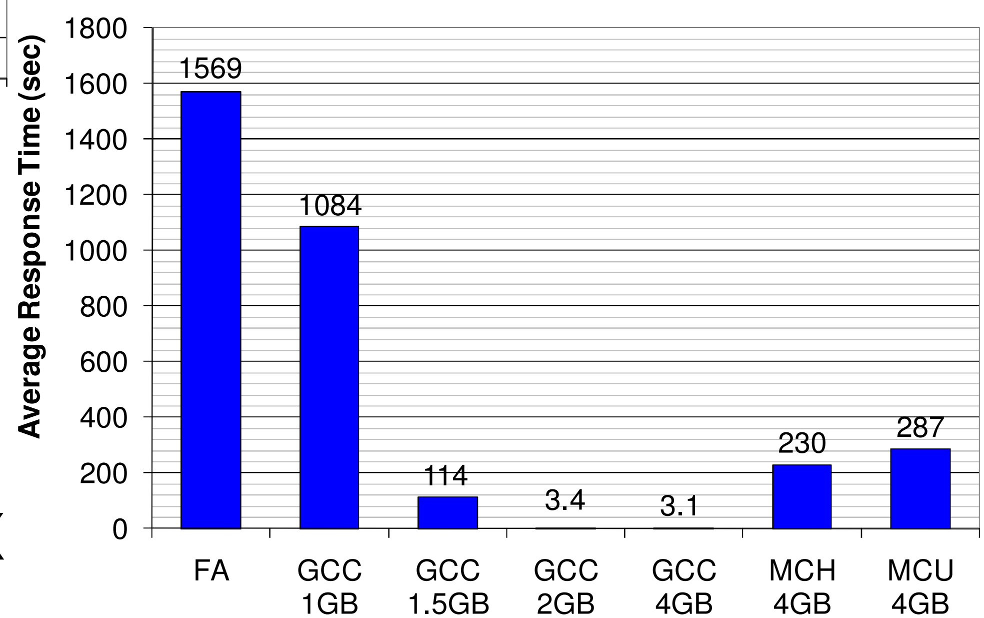
Data Diffusion
Monotonically Increasing Workload



- ← Throughput:
  - Average: 14Gb/s vs 4Gb/s
  - Peak: 81Gb/s vs. 6Gb/s



- Response Time →
  - 3 sec vs 1569 sec → 506X

[HPDC09] “The Quest for Scalable Support of Data Intensive Applications in Distributed Systems”, under review

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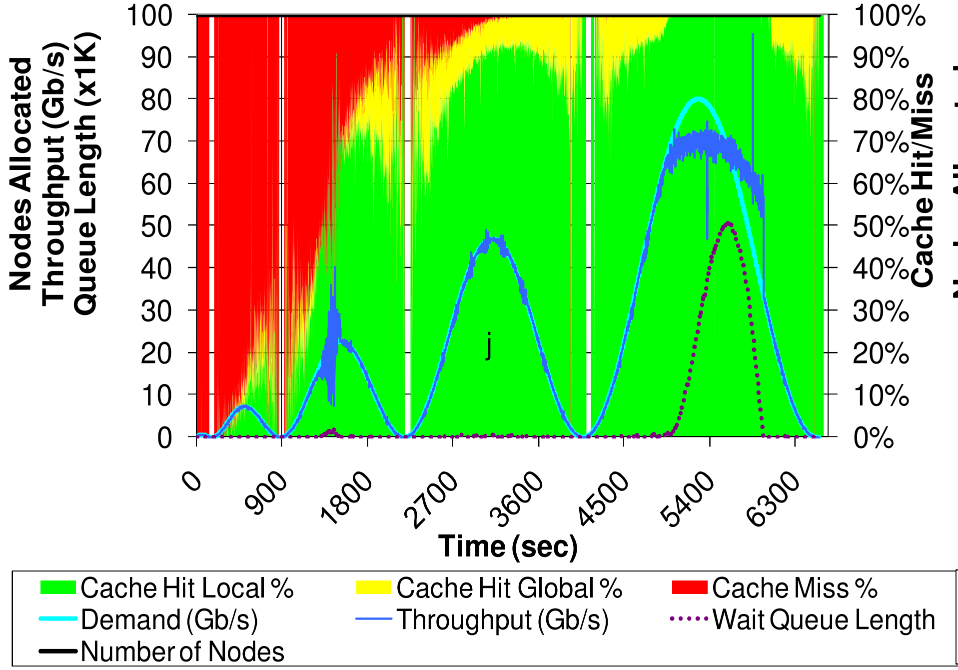
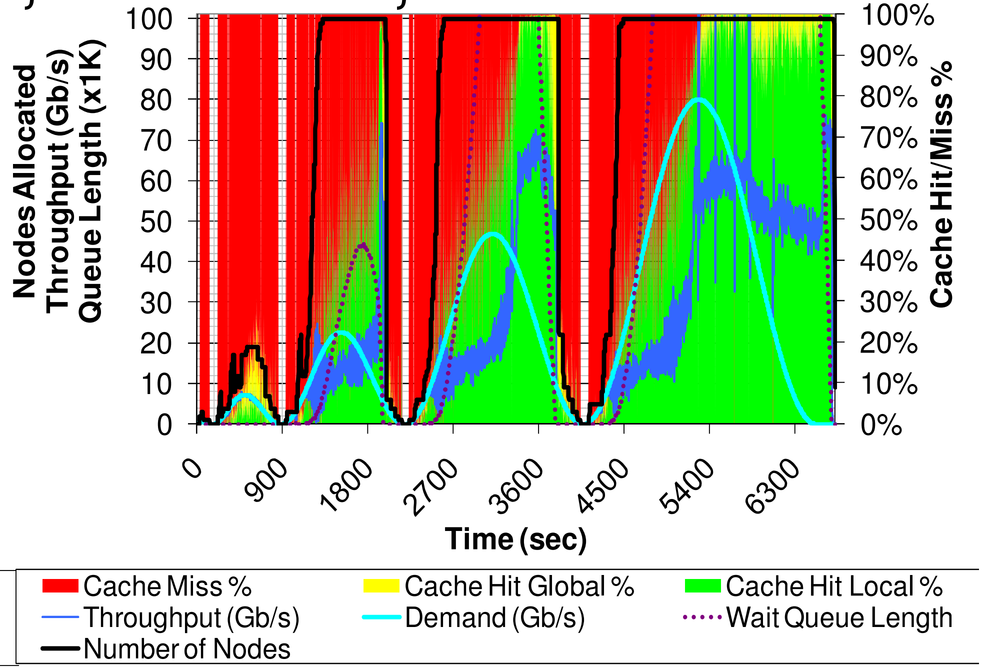
Data Diffusion
Sine-Wave Workload

- GPFS ➔ 5.7 hrs, ~8Gb/s, 1138 CPU hrs
- GCC+SRP ➔ 1.8 hrs, ~25Gb/s, 361 CPU hrs
- GCC+DRP ➔ 1.86 hrs, ~24Gb/s, 253 CPU hrs





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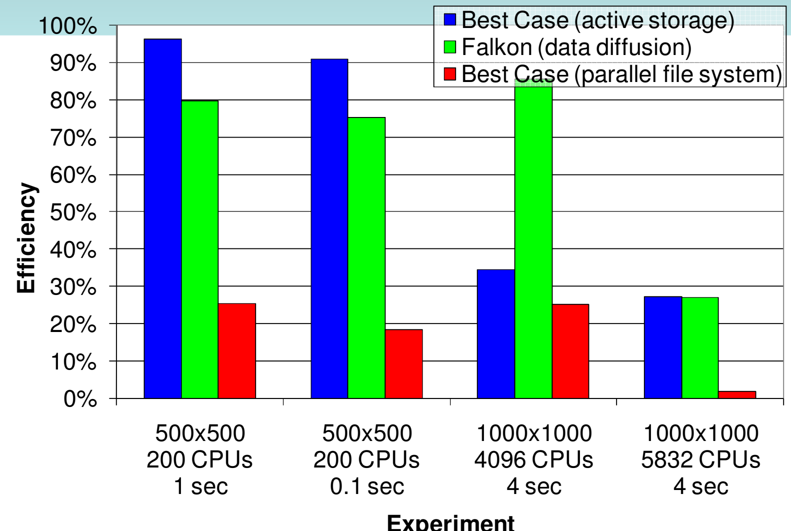
Data Diffusion vs. Active Storage All-Pairs Workload

- Pull vs. Push
  - Data Diffusion
    - Pulls ***task*** working set
    - Incremental spanning forest
  - Active Storage:
    - Pushes ***workload*** working set to all nodes
    - Static spanning tree



Experiment	Approach	Local Disk/Memory (GB)	Network (node-to-node) (GB)	Shared File System (GB)
500x500 200 CPUs 1 sec	Best Case (active storage)	6000	1536	12
	Falkon (data diffusion)	6000	1698	34
500x500 200 CPUs 0.1 sec	Best Case (active storage)	6000	1536	12
	Falkon (data diffusion)	6000	1528	62
1000x1000 4096 CPUs 4 sec	Best Case (active storage)	24000	12288	24
	Falkon (data diffusion)	24000	4676	384
1000x1000 5832 CPUs 4 sec	Best Case (active storage)	24000	12288	24
	Falkon (data diffusion)	24000	3867	906

Christopher Moretti, Douglas Thain, University of Notre Dame

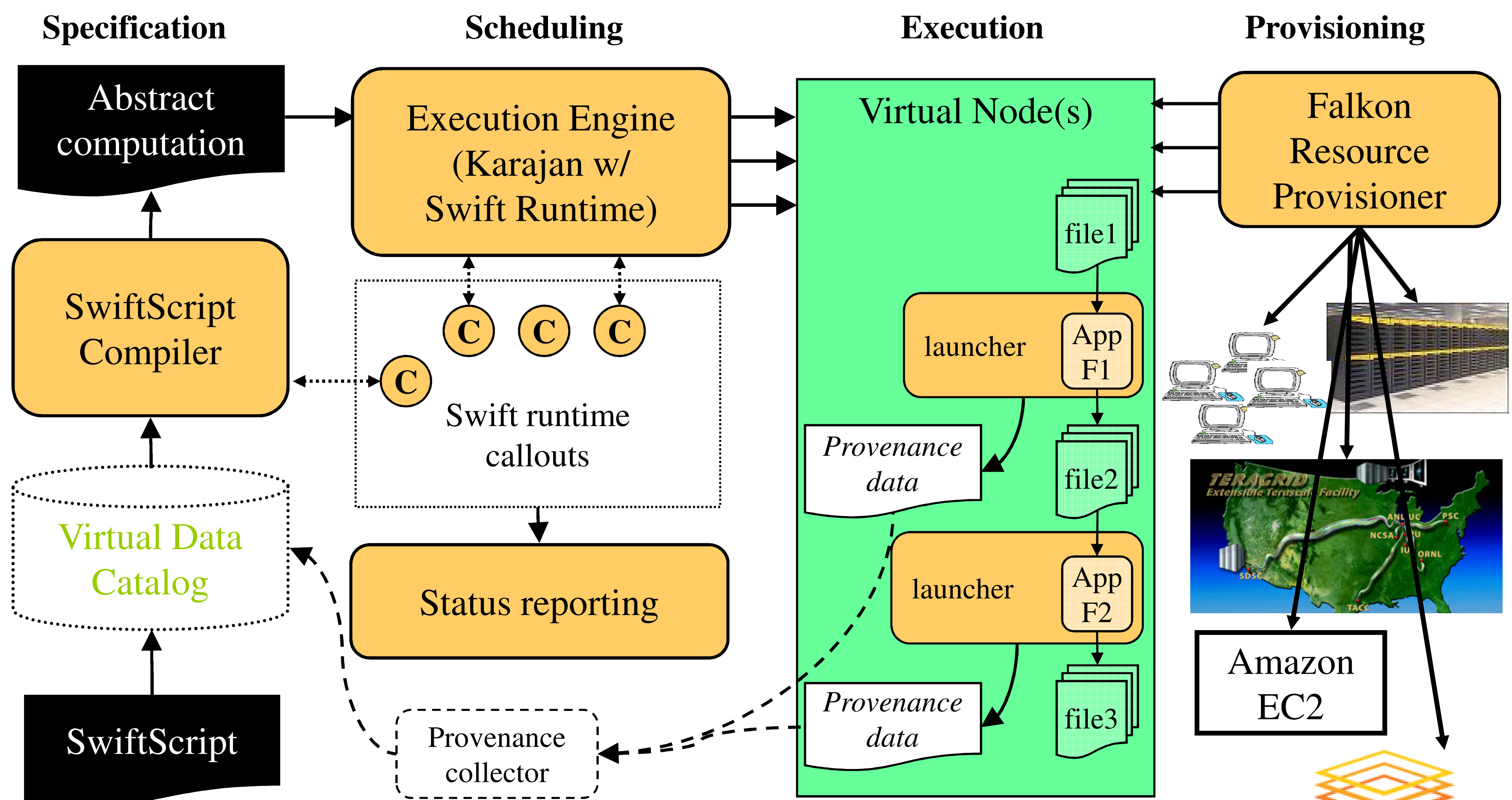
[HPDC09] "The Quest for Scalable Support of Data Intensive Applications in Distributed Systems", under review
[DIDC09] "Towards Data Intensive Many-Task Computing", under review

Data Diffusion vs. Active Storage All-Pairs Workload

- Best to use active storage if
  - Slow data source
  - Workload working set fits on local node storage
- Best to use data diffusion if
  - Medium to fast data source
  - Task working set << workload working set
  - Task working set fits on local node storage
- If task working set does not fit on local node storage
  - Use parallel file system (i.e. GPFS, Lustre, PVFS, etc)

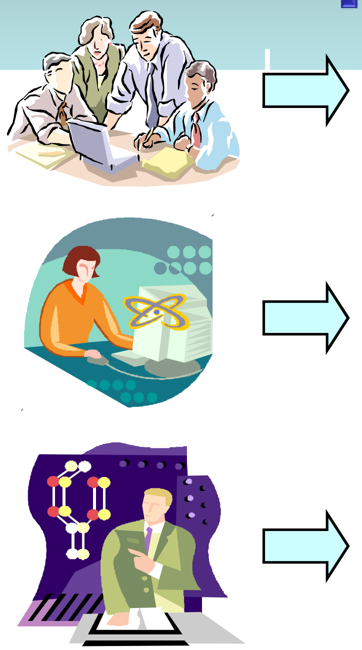
[HPDC09] "The Quest for Scalable Support of Data Intensive Applications in Distributed Systems", under review
[DIDC09] "Towards Data Intensive Many-Task Computing", under review

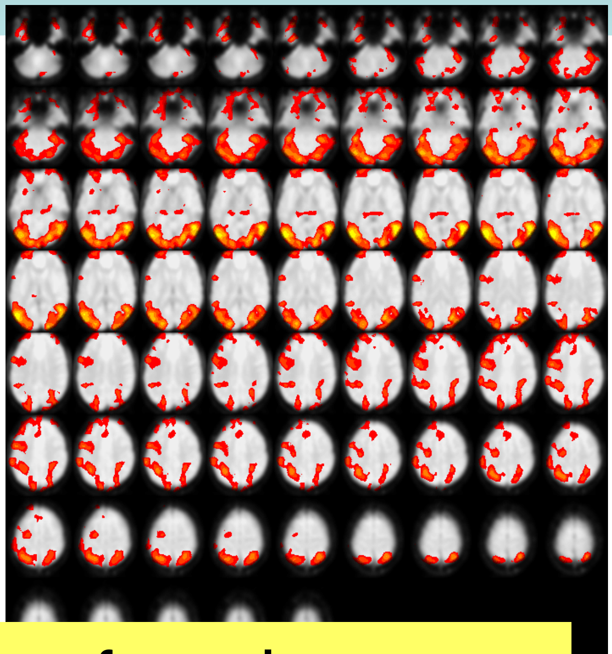
Applications
Swift Architecture

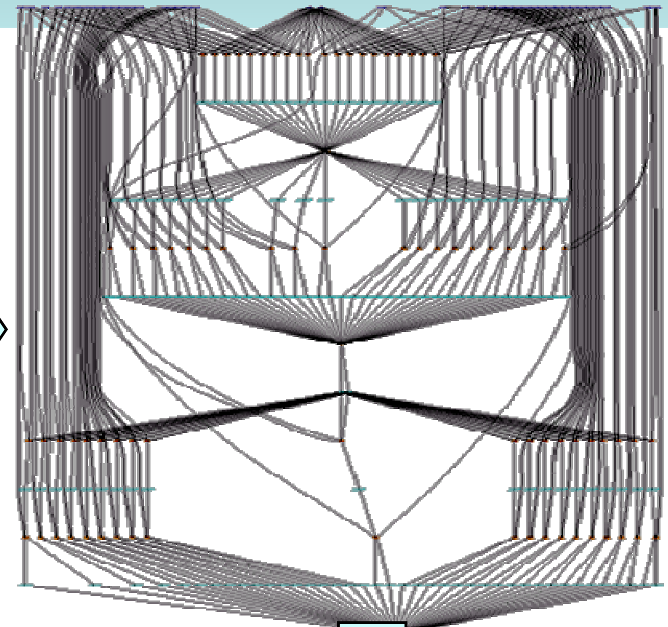


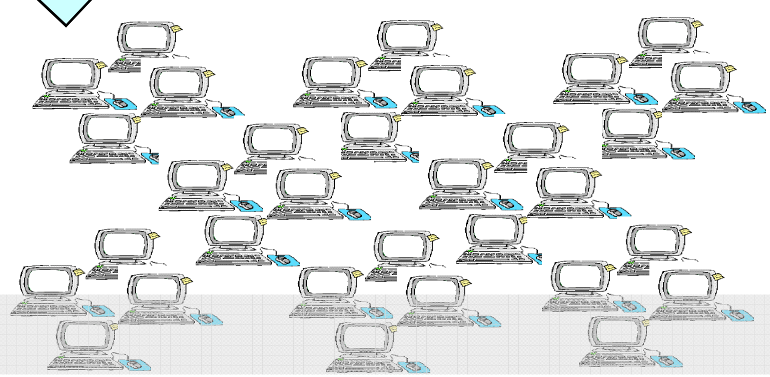
[NOVA08] "Realizing Fast, Scalable and Reliable Scientific Computations in Grid Environments"
[SWF07] "Swift: Fast, Reliable, Loosely Coupled Parallel Computation"

Applications
Medical Imaging: fMRI







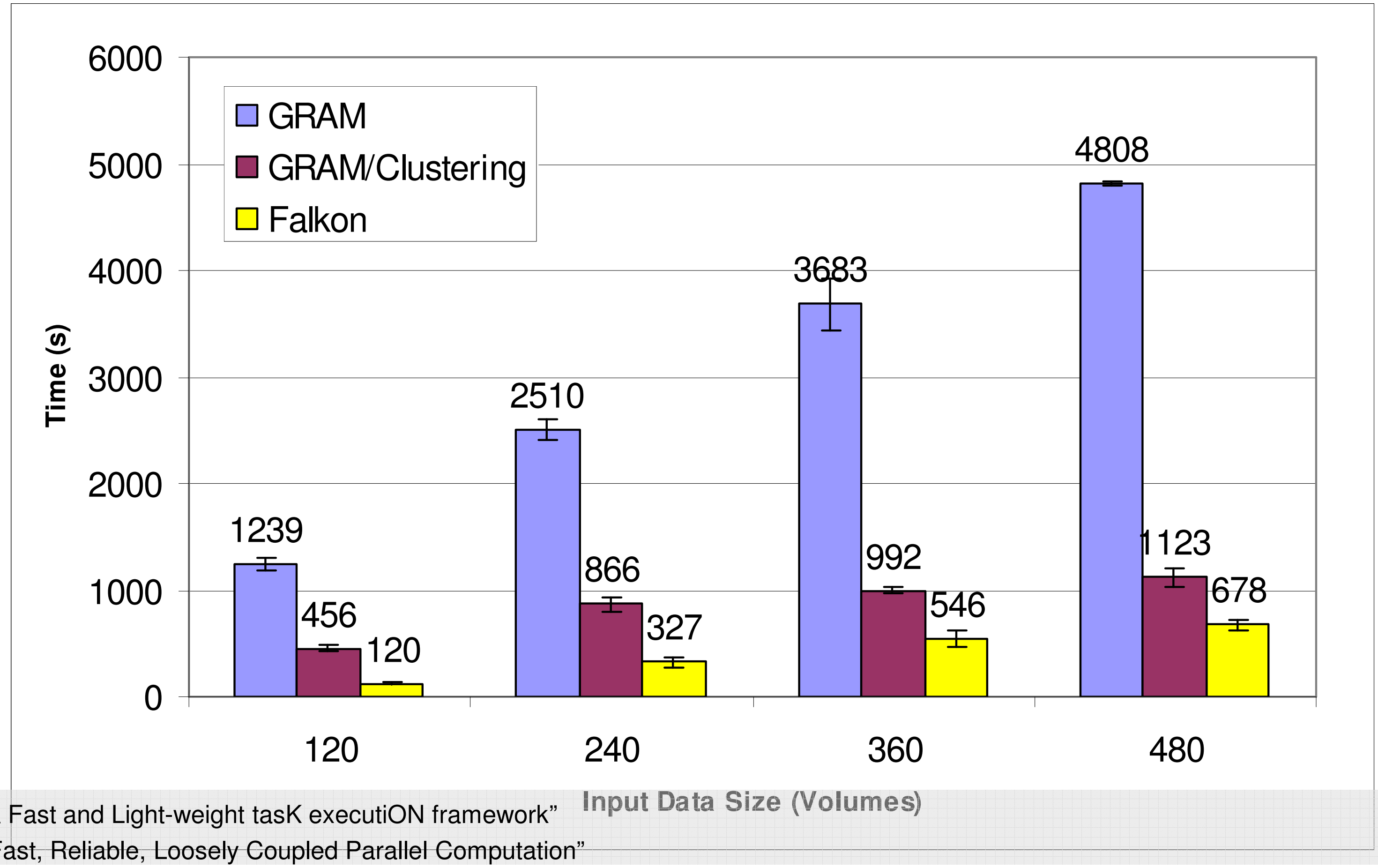


- Wide range of analyses
  - Testing, interactive analysis, production runs
  - Data mining
  - Parameter studies

[SC07] "Falkon: a Fast and Light-weight tasK executiON framework"
[SWF07] "Swift: Fast, Reliable, Loosely Coupled Parallel Computation"

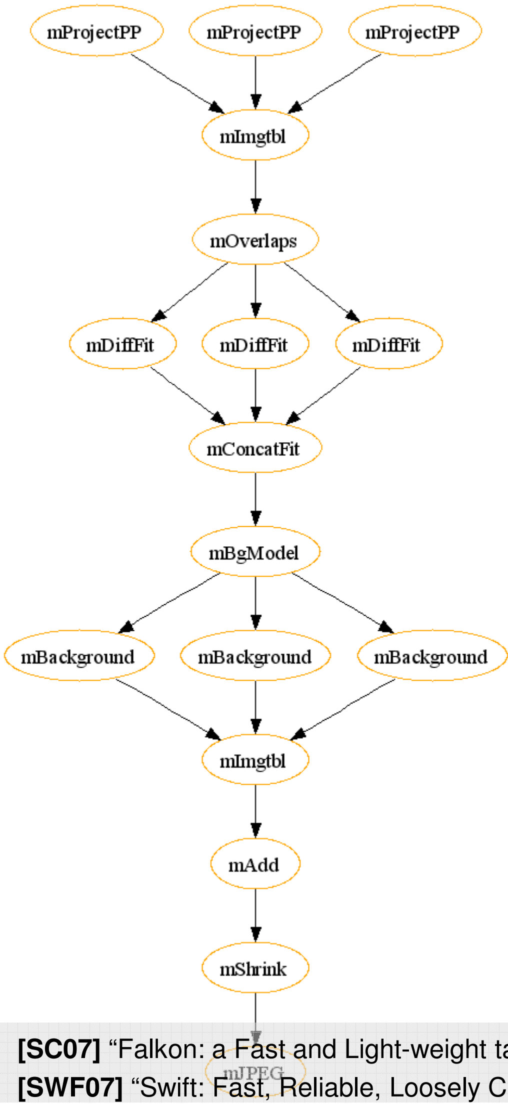
Applications
Medical Imaging: fMRI

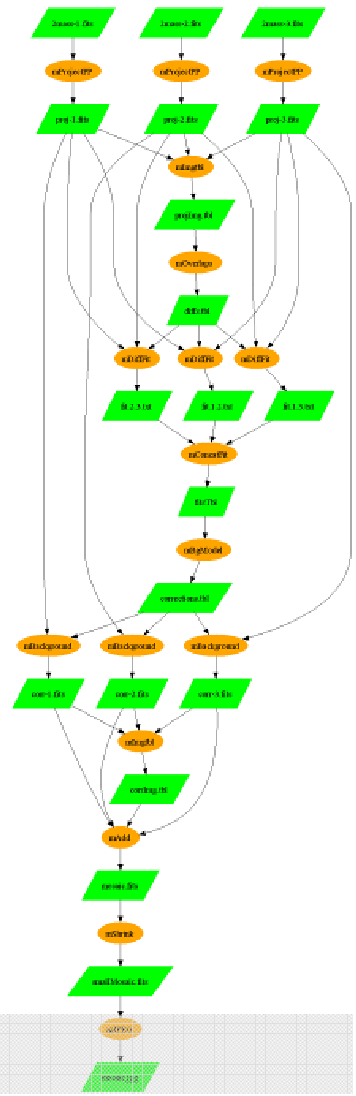
- GRAM vs. Falkon: 85%~90% lower run time
- GRAM/Clustering vs. Falkon: 40%~74% lower run time



[SC07] "Falkon: a Fast and Light-weight tasK executiON framework"
[SWF07] "Swift: Fast, Reliable, Loosely Coupled Parallel Computation"

Applications
Astronomy: Montage



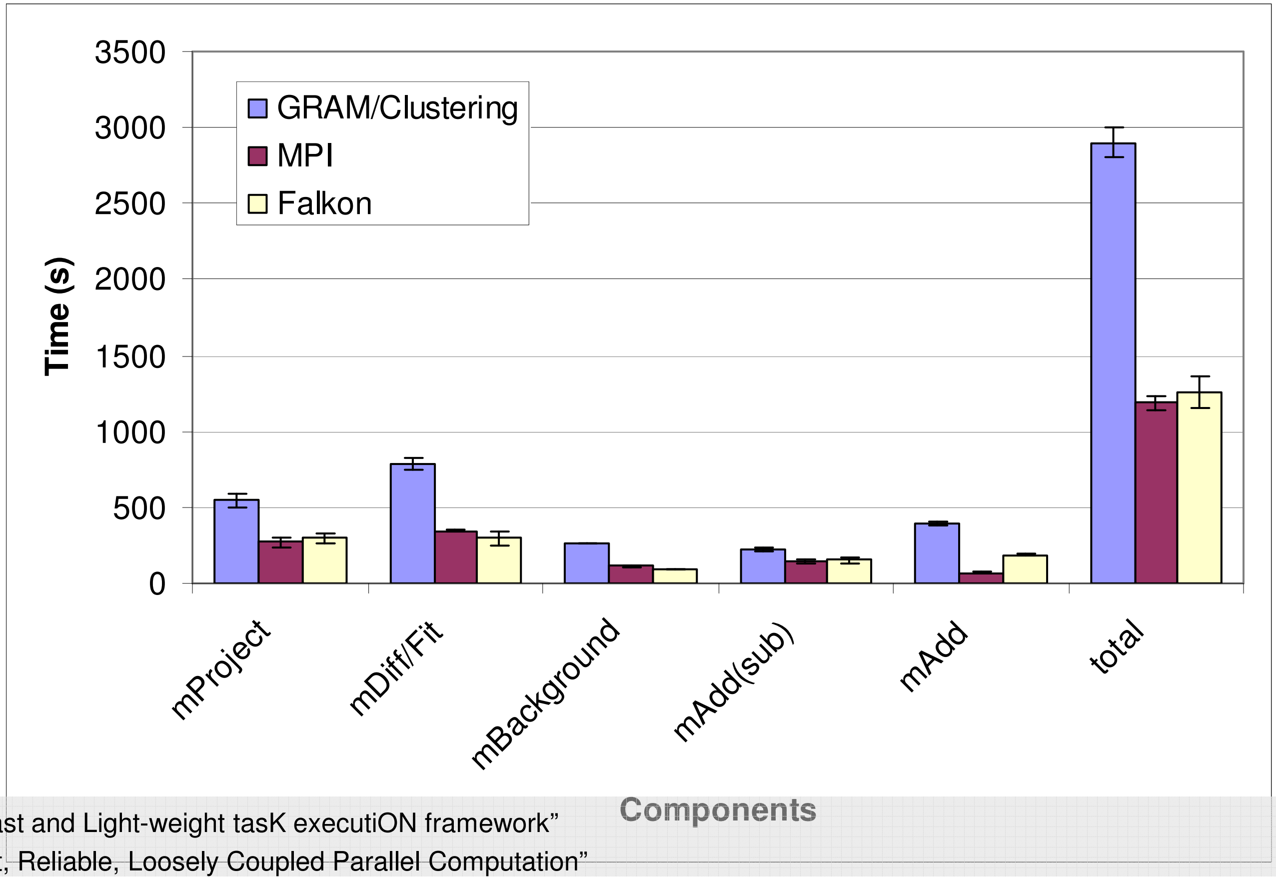


B. Berriman, J. Good (Caltech)
J. Jacob, D. Katz (JPL)

[SC07] “Falkon: a Fast and Light-weight tasK executiON framework”
[SWF07] “Swift: Fast, Reliable, Loosely Coupled Parallel Computation”

Applications
Astronomy: Montage

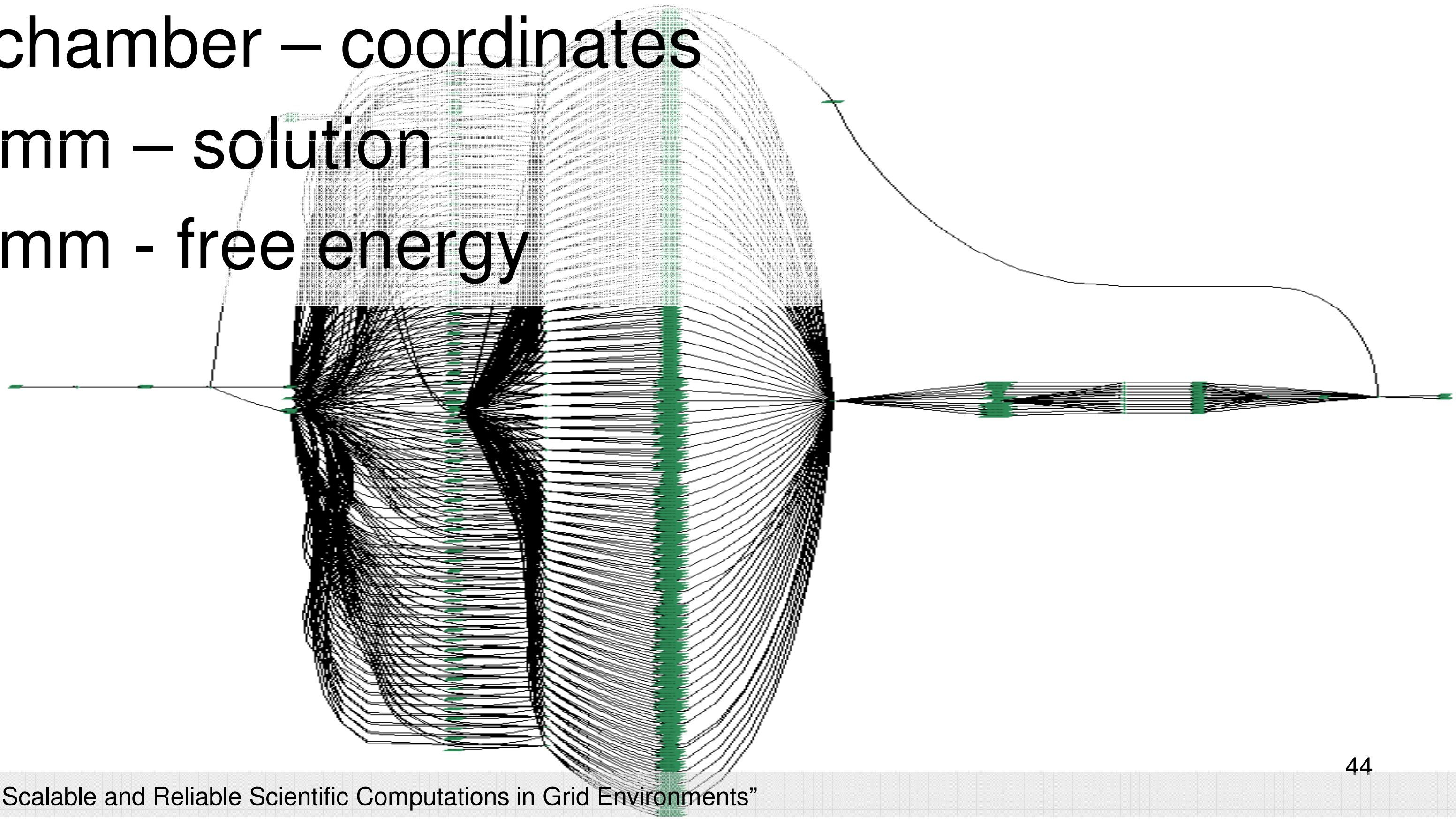
- GRAM/Clustering vs. Falkon: 57% lower application run time
- MPI* vs. Falkon: 4% higher application run time
- * MPI should be lower bound



[SC07] "Falkon: a Fast and Light-weight tasK executiON framework"
[SWF07] "Swift: Fast, Reliable, Loosely Coupled Parallel Computation"

Applications
Molecular Dynamics: MolDyn

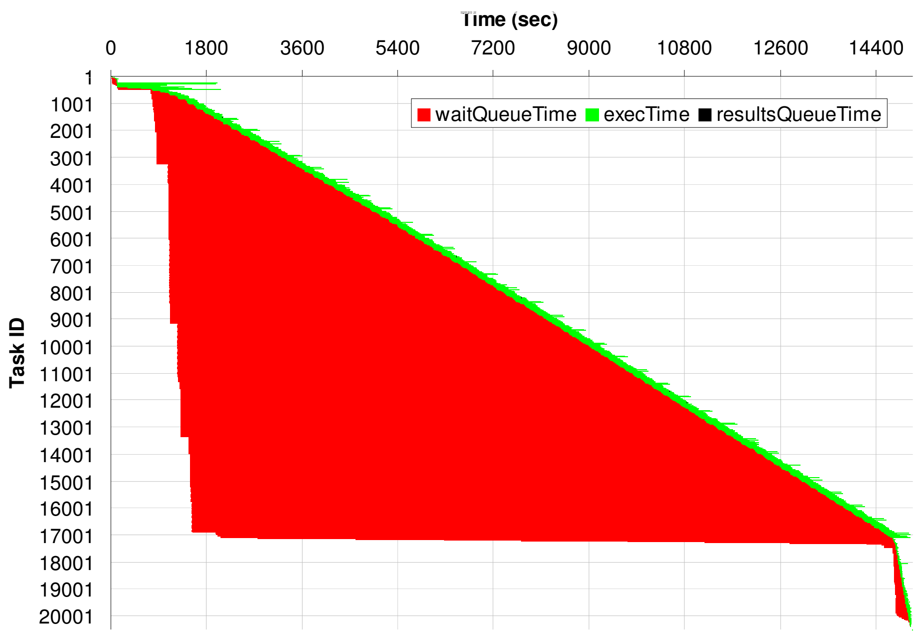
- Determination of free energies in aqueous solution
  - Antechamber – coordinates
  - Charmm – solution
  - Charmm - free energy

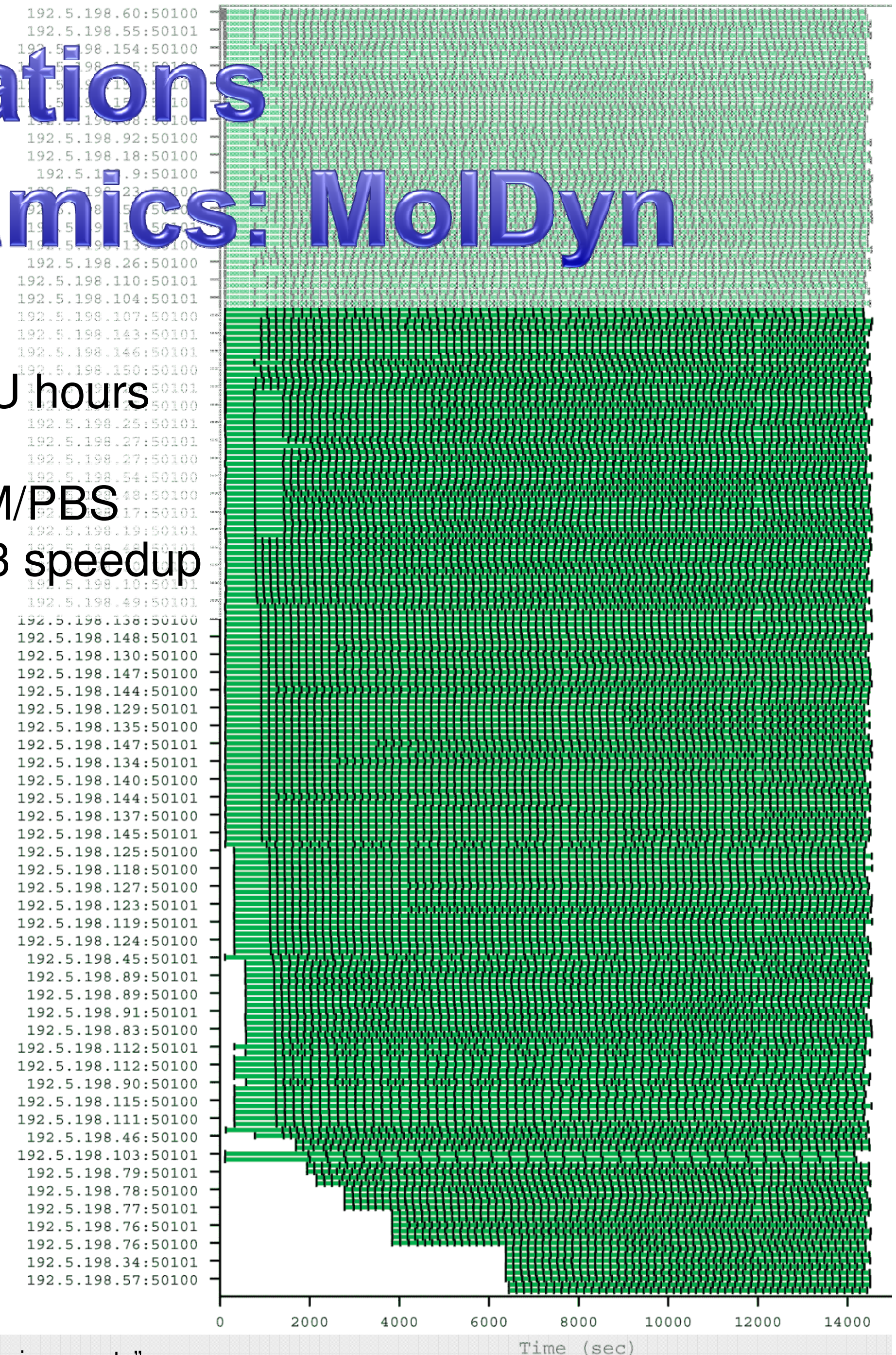


[NOVA08] "Realizing Fast, Scalable and Reliable Scientific Computations in Grid Environments"

Applications
Molecular Dynamics: MolDyn

- 244 molecules → 20497 jobs
- 15091 seconds on 216 CPUs → 867.1 CPU hours
- Efficiency: 99.8%
- Speedup: 206.9x → 8.2x faster than GRAM/PBS
- 50 molecules w/ GRAM (4201 jobs) → 25.3 speedup

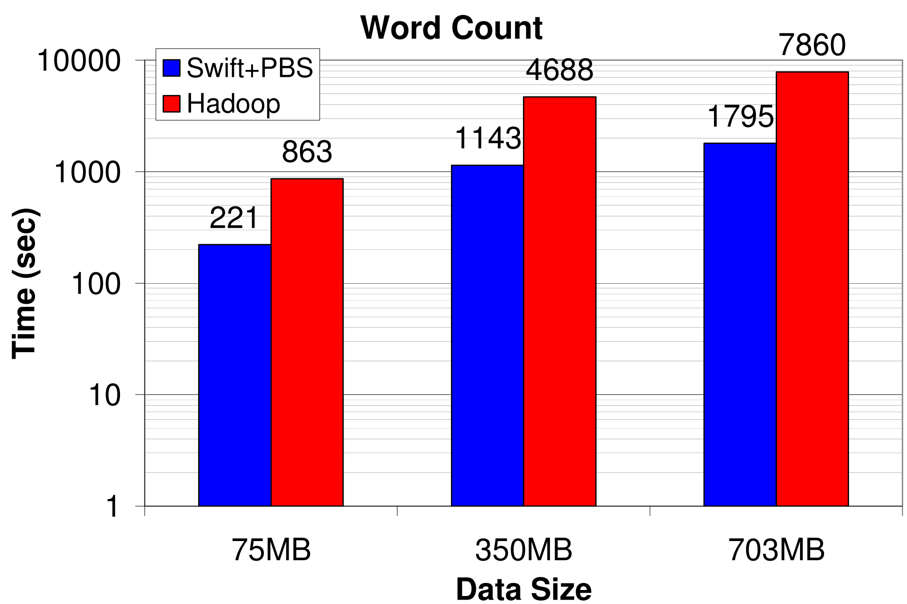


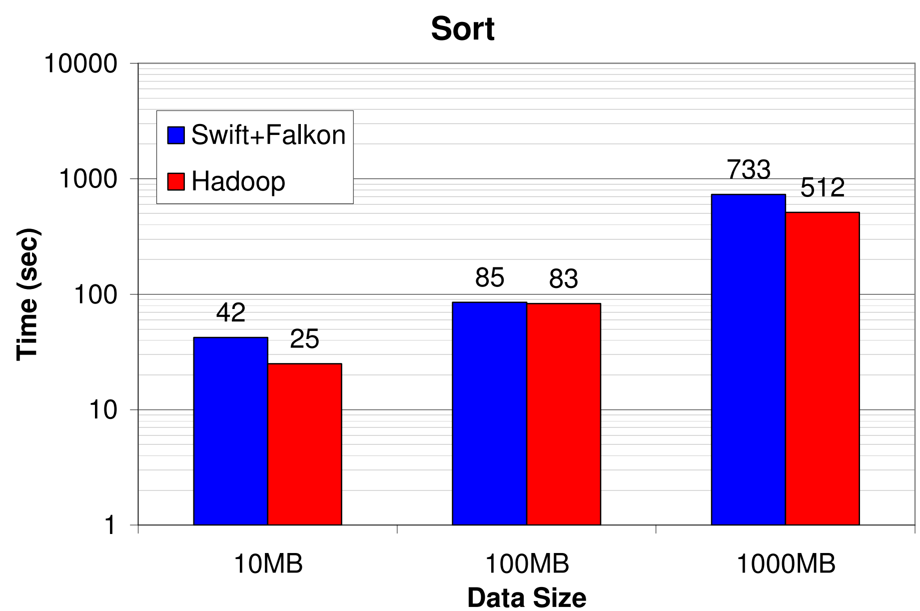


[NOVA08] "Realizing Fast, Scalable and Reliable Scientific Computations in Grid Environments"

Applications
Word Count and Sort

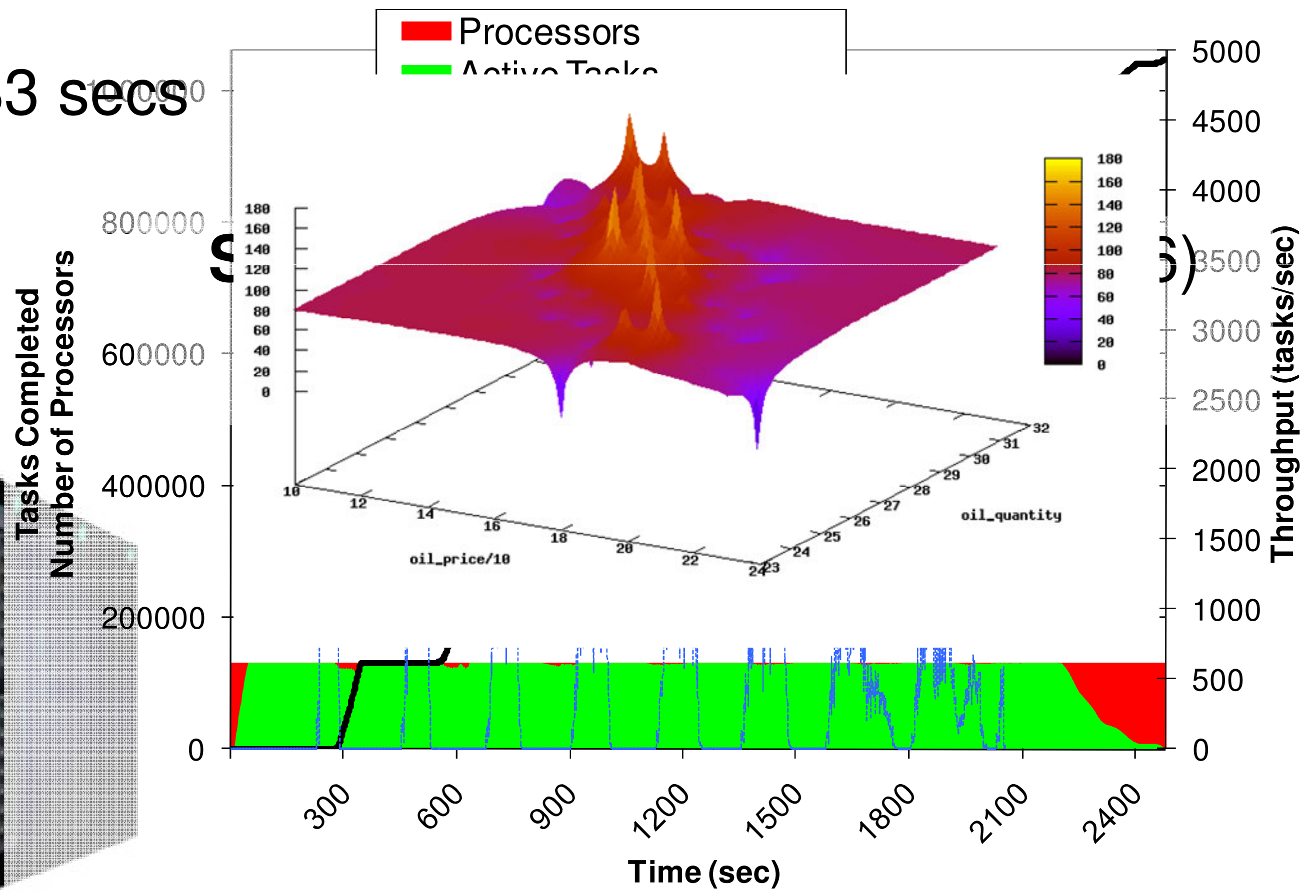
- Classic benchmarks for MapReduce
  - Word Count
  - Sort
- Swift and Falkon performs similar or better than Hadoop (on 32 processors)





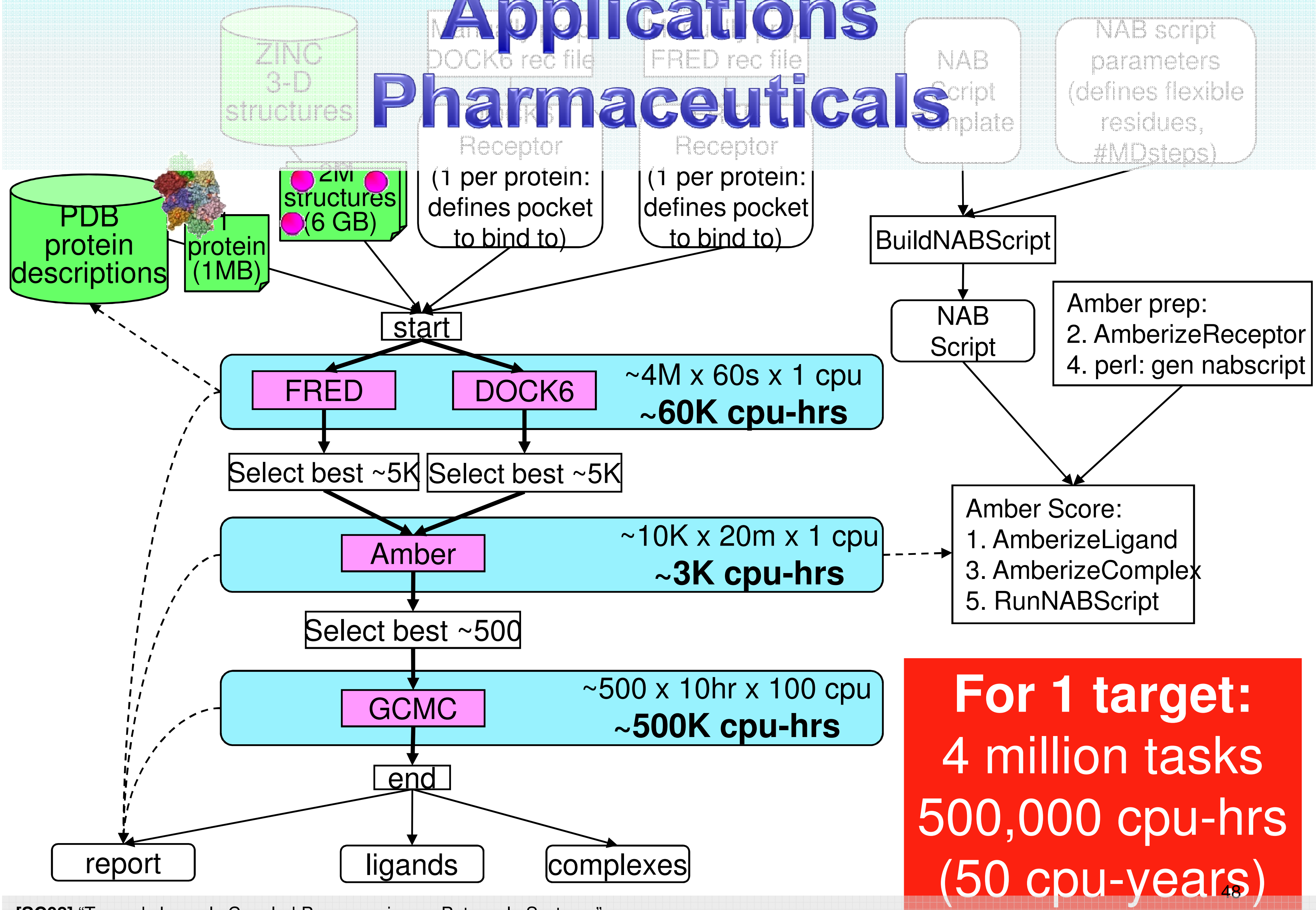
Applications
Economic Modeling: MARS

- CPU Cores: 130816
- Tasks: 1048576
- Elapsed time: 2483 secs
- CPU Years: 9.3



[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"

Applications Pharmaceuticals



[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"

Applications
Pharmaceuticals: DOCK

CPU cores: 118784

Tasks: 934803

Elapsed time: 2.01 hours

Compute time: 21.43 CPU years

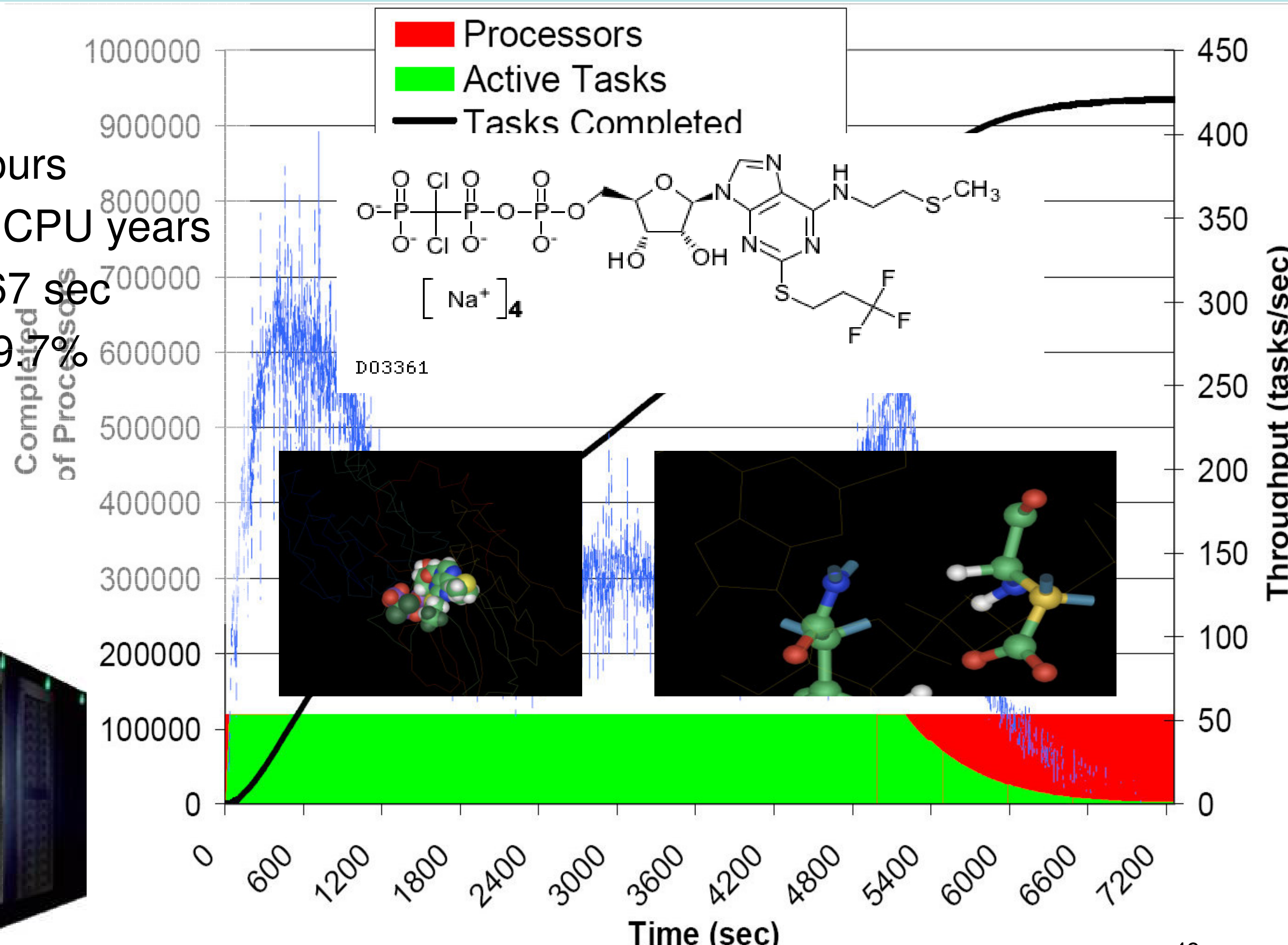
Average task time: 667 sec

Relative Efficiency: 99.7%

(from 16 to 32 racks)

Utilization:

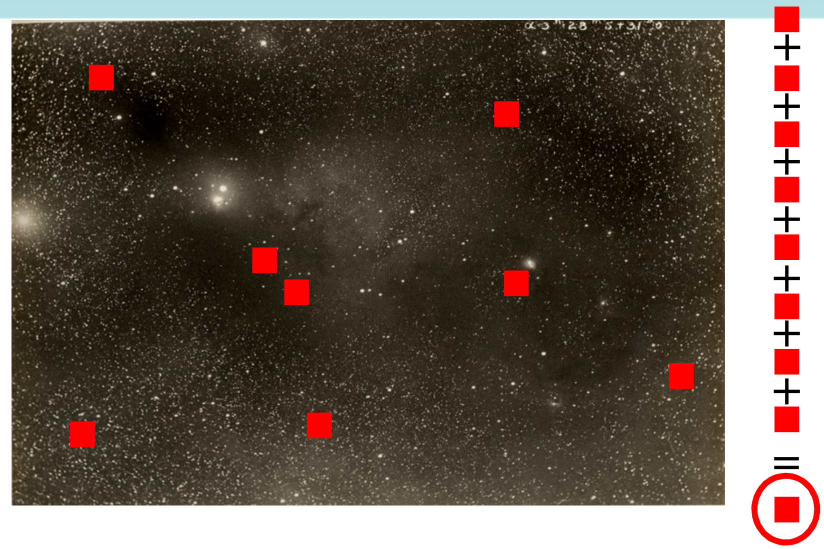
- Sustained: 99.6%
- Overall: 78.3%

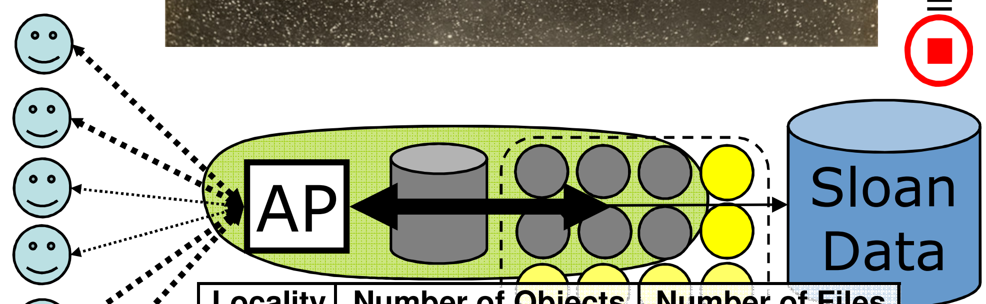


[SC08] "Towards Loosely-Coupled Programming on Petascale Systems"

Applications
Astronomy: AstroPortal

- Purpose
  - On-demand “stacks” of random locations within ~10TB dataset
- Challenge
  - Processing Costs:
    - O(100ms) per object
  - Data Intensive:
    - 40MB:1sec
  - Rapid access to 10-10K “random” files
  - Time-varying load



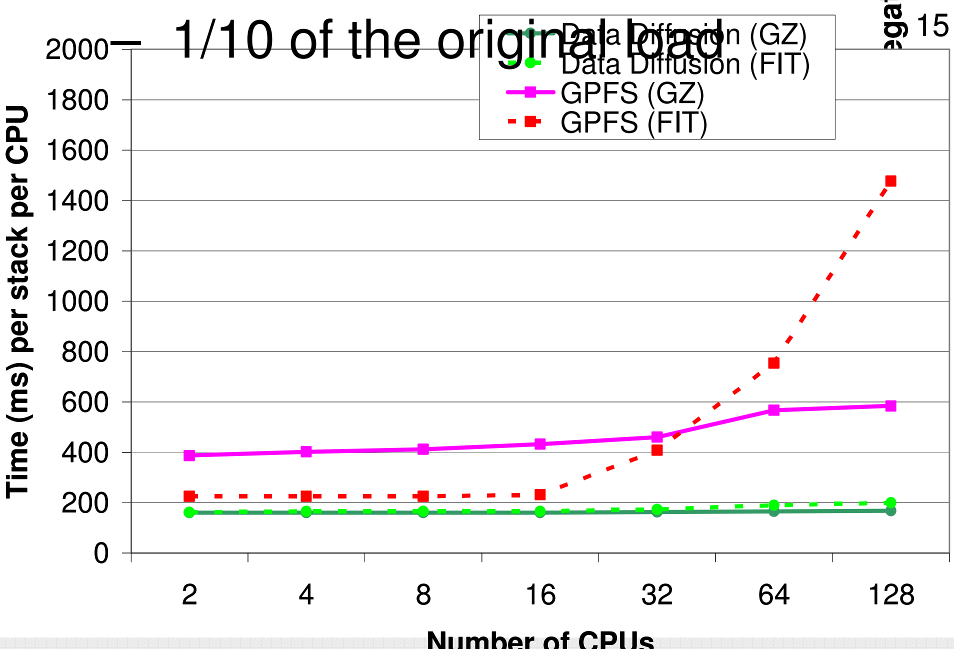


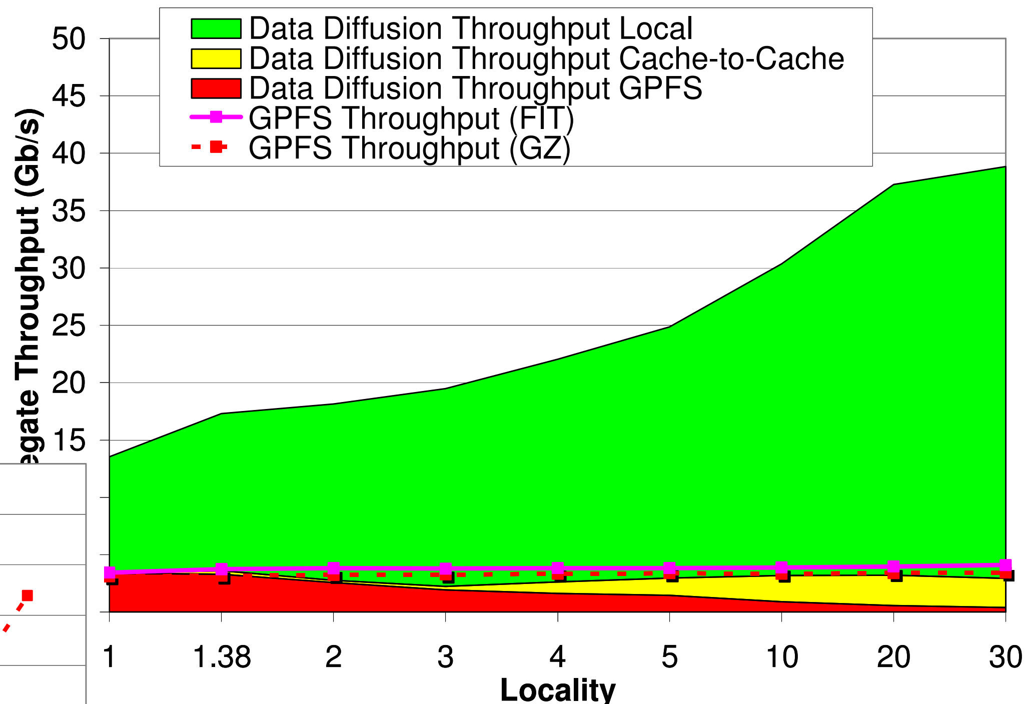
Locality	Number of Objects	Number of Files
1	111700	111700
1.38	154345	111699
2	97999	49000
3	88857	29620
4	76575	19145
5	60590	12120
10	46480	4650
20	40460	2025
30	23695	790

[DADC08] “Accelerating Large-scale Data Exploration through Data Diffusion”
[TG06] “AstroPortal: A Science Gateway for Large-scale Astronomy Data Analysis”

Applications
Astronomy: AstroPortal

- Aggregate throughput:
  - 39Gb/s
  - 10X higher than GPFS
- Reduced load on GPFS
  - 0.49Gb/s
  - 1/10 of the original load





- High data locality
  - Near perfect scalability

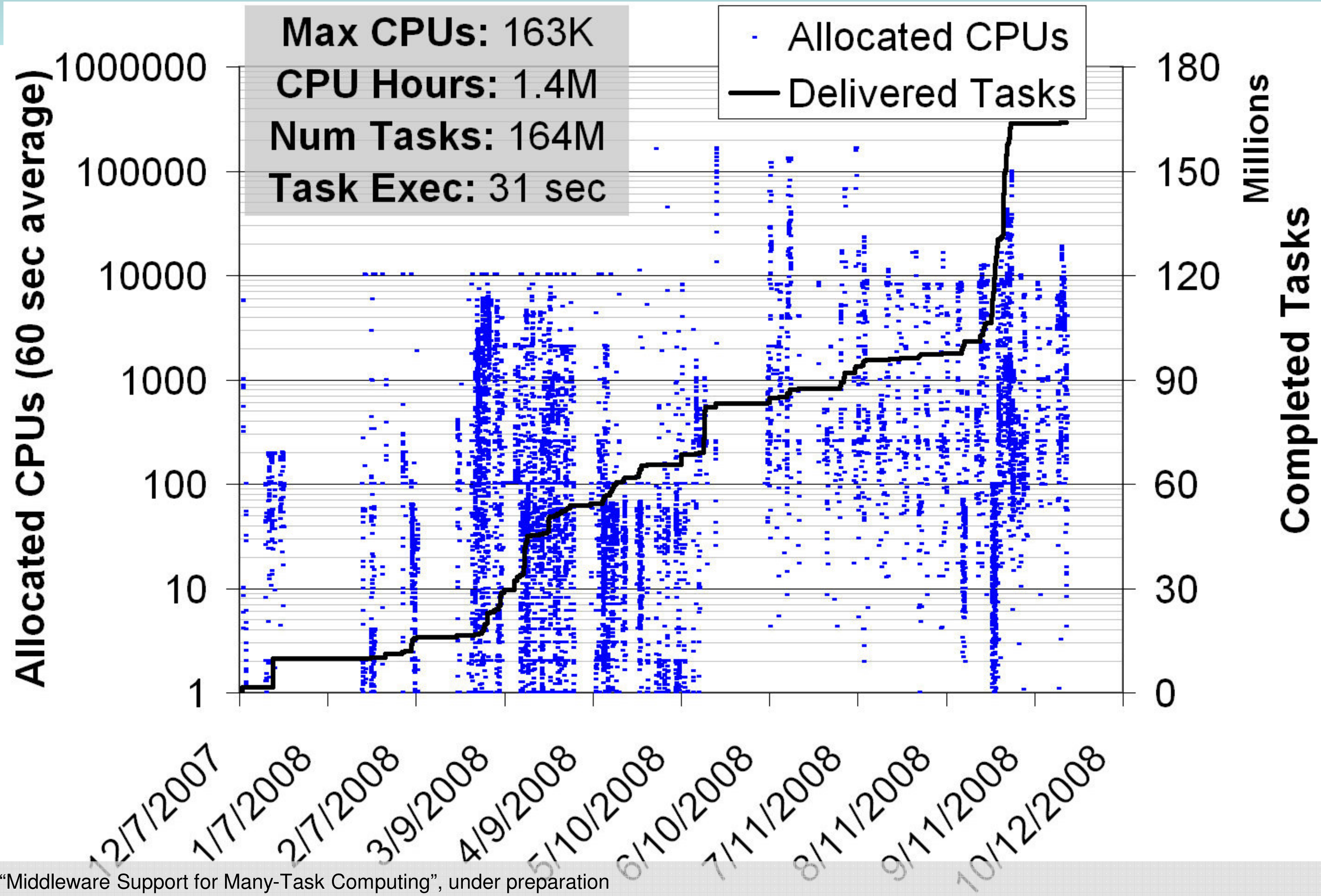
[DADC08] "Accelerating Large-scale Data Exploration through Data Diffusion"

Falkon Project

- Falkon is a real system
  - Late 2005: Initial prototype, AstroPortal
  - January 2007: Falkon v0
  - November 2007: Globus incubator project v0.1
    - http://dev.globus.org/wiki/Incubator/Falkon
  - February 2009: Globus incubator project v0.9
- Implemented in Java (~20K lines) and C (~1K lines)
  - Based on the Globus Toolkit 4.0
  - Open source: svn co https://svn.globus.org/repos/falkon
- Source code contributors (beside myself)
  - Yong Zhao, Zhao Zhang, Ben Clifford, Mihael Hategan, Gabriela Turcu
- Ideas contributors
  - Ian Foster, Mike Wilde, Catalin Dumitrescu, Alex Szalay, Jim Gray, …

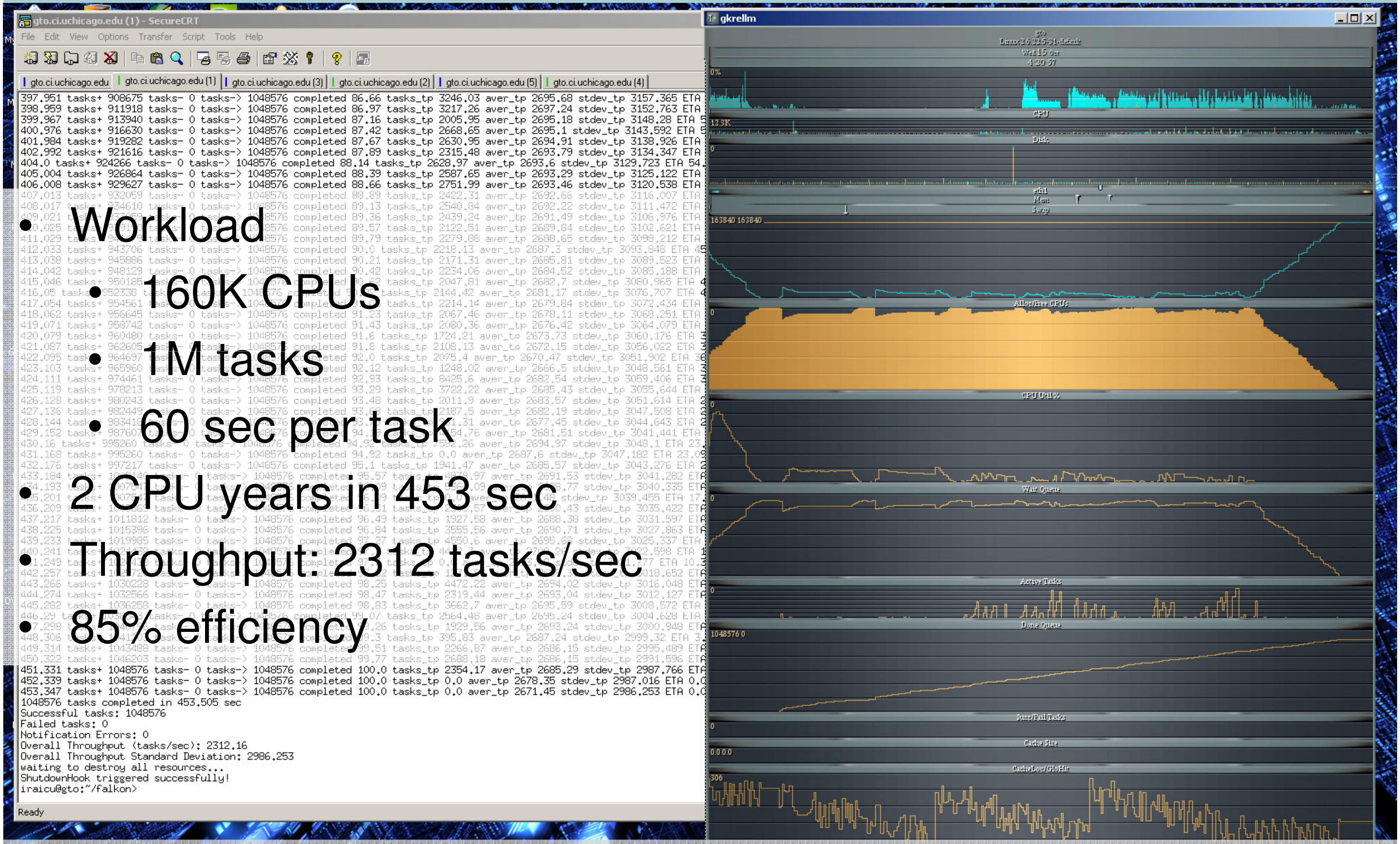
[Globus07] "Falkon: A Proposal for Project Globus Incubation"

Falkon Activity History (10 months)



[JS09] "Middleware Support for Many-Task Computing", under preparation

Falkon Monitoring



- Workload
  - 160K CPUs
  - 1M tasks
  - 60 sec per task
- 2 CPU years in 453 sec
- Throughput: 2312 tasks/sec
- 85% efficiency

[JS09] “Middleware Support for Many-Task Computing”, under preparation

Related Work: Local Resource Management

- [**Litzkow88**]: Condor
- [**Bode00**]: Portable Batch System (PBS)
- [**Zhou92**]: Load Sharing Facility (LSF)
- [**Gentzsch01**]: Sun Grid Engine (SGE)
- [**Anderson04**]: BOINC volunteer computing
- [**Desai05**]: Cobalt

Conclusion*:*

- *Most supported HPC and/or HTC, but due to relatively heavy-weight implementations they are not suitable for MTC*
- *None addressed data intensive workloads with data-aware schedulers*

Related Work: Resource Provisioning

- [**Banga99,Stankovic99**]: Muliti-Level Scheduling
- [**Appleby01**]: Oceano - SLA Based Management of a Computing Utility
- [**Frey02**,**Mehta06**]: Condor glide-ins
- [**Walker06**]: MyCluster (based on Condor glide-ins)
- [**Ramakrishnan06**]: Grid Hosting with Adaptive Resource Control
- [**Bresnahan06**]: Provisioning of bandwidth
- [**Singh06**]: Simulations

Conclusion*: None allowed for dynamic resizing of resource pool (independent of application logic) based on system load*

Related Work: Data Management

- **[Ghemawat03,Dean04]**: MapReduce+GFS
- **[Bialecki05]**: Hadoop+HDFS
- **[Gu06]**: Sphere+Sector
- **[Tatebe04]**: Gfarm
- **[Chervenak04]**: RLS, DRS
- **[Kosar06]**: Stork

- **Conclusions**
  - *None focused on the co-location of storage and generic black box computations with data-aware scheduling while operating in a dynamic elastic environment*
  - *Swift + Falkon + Data Diffusion is arguably a more generic and powerful solution than MapReduce*

Contributions

- There is more to HPC than tightly coupled MPI, and more to HTC than embarrassingly parallel long jobs
  - MTC: Many-Task Computing
  - Addressed real challenges in resource management in large scale distributed systems to enable MTC
  - Covered many domains (via Swift and Falkon): astronomy, medicine, chemistry, molecular dynamics, economic modelling, and data analytics

Contributions

- Identified that data locality is crucial to the efficient use of large scale distributed systems for data-intensive applications ➔ Data Diffusion
  - Integrated streamlined task dispatching with data aware scheduling policies
  - Heuristics to maximize real world performance
  - Suitable for varying, data-intensive workloads
  - Proof of O(NM) Competitive Caching

Mythbusting

- ~~Embarrassingly Ha~~ppily parallel apps are trivial to run
  - Logistical problems can be tremendous
- Loosely coupled apps do not require “supercomputers”
  - Total computational requirements can be enormous
  - Individual tasks may be tightly coupled
  - Workloads frequently involve large amounts of I/O
  - Make use of idle resources from “supercomputers” via backfilling
  - Costs to run “supercomputers” per FLOP is among the best

“Impossible only means that you haven't found the solution yet.”

Anonymous

- Loosely coupled apps do not require specialized system software
  - Their requirements on the job submission and storage systems can be extremely large
- Shared/parallel file systems are good for all applications
  - They don’t scale proportionally with the compute resources
  - Data intensive applications don’t perform and scale well
  - Growing compute/storage gap

More Information

- More information: http://people.cs.uchicago.edu/~iraicu/
- Related Projects:
  - Falkon: http://dev.globus.org/wiki/Incubator/Falkon
  - Swift: http://www.ci.uchicago.edu/swift/index.php
- Dissertation Committee:
  - Ian Foster, The University of Chicago & Argonne National Laboratory
  - Rick Stevens, The University of Chicago & Argonne National Laboratory
  - Alex Szalay, The Johns Hopkins University
- People contributing ideas, slides, source code, applications, results, etc
  - Ian Foster, Alex Szalay, Rick Stevens, Mike Wilde, Jim Gray, Catalin Dumitrescu, Yong Zhao, Zhao Zhang, Gabriela Turcu, Ben Clifford, Mihael Hategan, Allan Espinosa, Kamil Iskra, Pete Beckman, Philip Little, Christopher Moretti, Amitabh Chaudhary, Douglas Thain, Quan Pham, Atilla Balkir, Jing Tie, Veronika Nefedova, Sarah Kenny, Gregor von Laszewski, Tiberiu Stef-Praun, Julian Bunn, Andrew Binkowski , Glen Hocky, Donald Hanson, Matthew Cohoon, Fangfang Xia, Mike Kubal, …
- Funding:
  - **NASA**: Ames Research Center, Graduate Student Research Program
    - Jerry C. Yan, NASA GSRP Research Advisor
  - **DOE**: Mathematical, Information, and Computational Sciences Division subprogram of the Office of Advanced Scientific Computing Research, Office of Science, U.S. Dept. of Energy
  - **NSF**: TeraGrid

Publications Central to Dissertation
(2006 – 2009)

1. Ioan Raicu, Ian Foster, Yong Zhao, Alex Szalay, Philip Little, Christopher M. Moretti, Amitabh Chaudhary, Douglas Thain. “Towards Data Intensive Many-Task Computing”, under review as a book chapter in “Data Intensive Distributed Computing: Challenges and Solutions for Large-Scale Information Management”, IGI Global Publishers
2. Ioan Raicu, Ian Foster, Yong Zhao, Philip Little, Christopher Moretti, Amitabh Chaudhary, Douglas Thain. “The Quest for Scalable Support of Data Intensive Workloads in Distributed Systems”, under review at ACM HPDC09
3. Ioan Raicu, Ian Foster, Yong Zhao. “Many-Task Computing for Grids and Supercomputers”, Invited Paper, IEEE Workshop on Many-Task Computing on Grids and Supercomputers (MTAGS08), 2008
4. Ian Foster, Yong Zhao, Ioan Raicu, Shiyong Lu. “Cloud Computing and Grid Computing 360-Degree Compared”, IEEE Grid Computing Environments (GCE08) 2008.
5. Zhao Zhang, Allan Espinosa, Kamil Iskra, Ioan Raicu, Ian Foster, Michael Wilde. “Design and Evaluation of a Collective I/O Model for Loosely-coupled Petascale Programming”, IEEE Workshop on Many-Task Computing on Grids and Supercomputers (MTAGS08) 2008.
6. Ioan Raicu, Zhao Zhang, Mike Wilde, Ian Foster, Pete Beckman, Kamil Iskra, Ben Clifford. “Towards Loosely-Coupled Programming on Petascale Systems”, IEEE/ACM Supercomputing 2008.
7. Ioan Raicu, Ian Foster. “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets: Year 2 Status and Year 3 Proposal”, GSRP, Ames Research Center, NASA, March 2008 -- Award funded 10/1/08 - 9/30/09.
8. Quan T. Pham, Atilla S. Balkir, Jing Tie, Ian Foster, Mike Wilde, Ioan Raicu. “Data Intensive Scalable Computing on TeraGrid: A Comparison of MapReduce and Swift”, Poster Presentation, TeraGrid Conference 2008.
9. Ioan Raicu, Yong Zhao, Ian Foster, Mike Wilde, Zhao Zhang, Ben Clifford, Mihael Hategan, Sarah Kenny. “Managing and Executing Loosely Coupled Large Scale Applications on Clusters, Grids, and Supercomputers”, Extended Abstract, GlobusWorld08, part of Open Source Grid and Cluster Conference 2008.
10. Yong Zhao, Ioan Raicu, Ian Foster. “Scientific Workflow Systems for 21st Century e-Science, New Bottle or New Wine?”, Invited Paper, IEEE Workshop on Scientific Workflows 2008.
11. Ioan Raicu, Yong Zhao, Ian Foster, Alex Szalay. "Accelerating Large-scale Data Exploration through Data Diffusion", Int. Workshop on Data-Aware Distributed Computing 2008.
12. Ioan Raicu, Ian Foster. “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets: Year 2 Status and Year 3 Proposal”, GSRP, Ames Research Center, NASA, February 2008.
13. Ioan Raicu, Ian Foster. “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets: Year 1 Final Report”, GSRP, Ames Research Center, NASA, February 2008.
14. Yong Zhao, Ioan Raicu, Ian Foster, Mihael Hategan, Veronika Nefedova, Mike Wilde. “Realizing Fast, Scalable and Reliable Scientific Computations in Grid Environments”, Book chapter in Grid Computing Research Progress, ISBN: 978-1-60456-404-4, Nova Publisher 2008.
15. Ioan Raicu. “Harnessing Grid Resources with Data-Centric Task Farms”, University of Chicago, Computer Science Department, PhD Proposal, December 2007, Chicago, Illinois.
16. Ioan Raicu, Yong Zhao, Catalin Dumitrescu, Ian Foster and Mike Wilde. “Falkon: A Proposal for Project Globus Incubation”, Globus Incubation Management Project, 2007 – Proposal accepted 11/10/07.
17. Ioan Raicu, Ian Foster. “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets: Year 1 Status and Year 2 Proposal”, GSRP, Ames Research Center, NASA, February 2007 -- Award funded 10/1/07 - 9/30/08.
18. Ioan Raicu, Yong Zhao, Ian Foster, Alex Szalay. “A Data Diffusion Approach to Large Scale Scientific Exploration”, Microsoft Research eScience Workshop 2007.
19. Ioan Raicu, Yong Zhao, Catalin Dumitrescu, Ian Foster, Mike Wilde. “Falkon: a Fast and Light-weight tasK executiON framework”, IEEE/ACM SuperComputing 2007.
20. Ioan Raicu, Catalin Dumitrescu, Ian Foster. “Dynamic Resource Provisioning in Grid Environments”, TeraGrid Conference 2007.
21. Yong Zhao, Mihael Hategan, Ben Clifford, Ian Foster, Gregor von Laszewski, Ioan Raicu, Tiberiu Stef-Praun, Mike Wilde. “Swift: Fast, Reliable, Loosely Coupled Parallel Computation”, IEEE Workshop on Scientific Workflows 2007.
22. Ioan Raicu, Ian Foster. “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets”, GSRP, Ames Research Center, NASA, February 2006 -- Award funded 10/1/06 - 9/30/07.
23. Ioan Raicu, Ian Foster, Alex Szalay. “Harnessing Grid Resources to Enable the Dynamic Analysis of Large Astronomy Datasets”, poster, IEEE/ACM SuperComputing 2006.
24. Ioan Raicu, Ian Foster, Alex Szalay, Gabriela Turcu. “AstroPortal: A Science Gateway for Large-scale Astronomy Data Analysis”, TeraGrid Conference 2006, June 2006.
25. Alex Szalay, Julian Bunn, Jim Gray, Ian Foster, Ioan Raicu. “The Importance of Data Locality in Distributed Computing Applications”, NSF Workflow Workshop 2006.

Other Publications (disjoint set)

(2002 – 2007)

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2. Catalin Dumitrescu, Alexandru Iosup, H. Mohamed, Dick H.J. Epema, Matei Ripeanu, Nicolae Tapus, Ioan Raicu, Ian Foster. "ServMark: A Framework for Testing Grids Services", IEEE Grid 2007.
3. Catalin Dumitrescu, Ioan Raicu, Ian Foster. "The Design, Usage, and Performance of GRUBER: A Grid uSLA-based Brokering Infrastructure", International Journal of Grid Computing, 2007.
4. Catalin Dumitrescu, Ioan Raicu, Ian Foster. "Usage SLA-based Scheduling in Grids", Journal on Concurrency and Computation: Practice and Experience, 2006.
5. Ioan Raicu, Catalin Dumitrescu, Matei Ripeanu, Ian Foster. "The Design, Performance, and Use of DiPerF: An automated DIstributed PERformance testing Framework", International Journal of Grid Computing, Special Issue on Global and Peer-to-Peer Computing, 2006.
6. Catalin Dumitrescu, Ioan Raicu, Ian Foster. "Performance Measurements in Running Workloads over a Grid", The 4th International Conference on Grid and Cooperative Computing (GCC), 2005
7. Catalin Dumitrescu, Ioan Raicu, Ian Foster. "DI-GRUBER: A Distributed Approach for Grid Resource Brokering", IEEE/ACM Super Computing 2005 (SC 2005)
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9. Ioan Raicu. "A Performance Study of the Globus Toolkit® and Grid Services via DiPerF, an automated DIstributed PERformance testing Framework", University of Chicago, Computer Science Department, MS Thesis, May 2005, Chicago, Illinois.
10. Ioan Raicu, Loren Schwiebert, Scott Fowler, Sandeep K.S. Gupta. "Local Load Balancing for Globally Efficient Routing in Wireless Sensor Networks", International Journal of Distributed Sensor Networks, 1: 163–185, 2005.
11. Ioan Raicu, Loren Schwiebert, Scott Fowler, Sandeep K.S. Gupta. "e3D: An Energy-Efficient Routing Algorithm for Wireless Sensor Networks", IEEE ISSNIP 2004 (The International Conference on Intelligent Sensors, Sensor Networks and Information Processing), 2004.
12. Catalin Dumitrescu, Ioan Raicu, Matei Ripeanu, Ian Foster. "DiPerF: an automated DIstributed PERformance testing Framework", IEEE/ACM GRID2004, Pittsburgh, PA, November 2004, pp 289 - 296
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